NEW

GADGETS & FUTURE TECH | ENTERTAINMENT | ENGINEERING | BIOTECH

Drones

Biometric fingerprinting

Amazing holograms

Next-gen security

NEW WITH OVER 1000 FACTS INSIDE

HOW IT WORKS BOOK OF

AMAZING TECHNOLOGY

Vol.3

How spies see everything

EVERYTHING YOU NEED TO KNOW ABOUT THE WORLD'S BEST TECH

The future of artificial intelligence

Discover interactive homes

Spy gadgets

How mobile phones work

Technology goes micro

Super-computers

WELCOME TO

HOW IT WORKS BOOK OF

AMAZING TECHNOLOGY

Vol.3

There's no doubt that technology in all its forms has become an integral part of our lives. Yet very few of us understand exactly how it all works. However, Volume 3 of the How It Works Book Of Amazing Technology will educate and inform readers about some of the world's most innovative gadgets, impressive constructions and unbelievable developments in artifical intelligence. With our in-depth guides, fascinating facts and detailed cutaway images, you'll learn about everything from the most sophisticated supercomputers to smart homes that will adapt to your habits. If you've ever wondered how you get signal on your mobile, how organs can be produced with 3D printing, or how robotic limbs communicate with our brain, you'll find all the answers right here.

HOW IT WORKS BOOK OF AMAZING TECHNOLOGY Vol. 3

Imagine Publishing Ltd
Richmond House
33 Richmond Hill
Bournemouth
Dorset BH2 6EZ
☎ +44 (0) 1202 586200
Website: www.imagine-publishing.co.uk
Twitter: @Books_Imagine
Facebook: www.facebook.com/ImagineBookazines

Publishing Director
Aaron Asadi

Head of Design
Ross Andrews

Production Editor
Sanne de Boer

Senior Art Editor
Greg Whitaker

Designer
Abbi Denney

Photographer
James Sheppard

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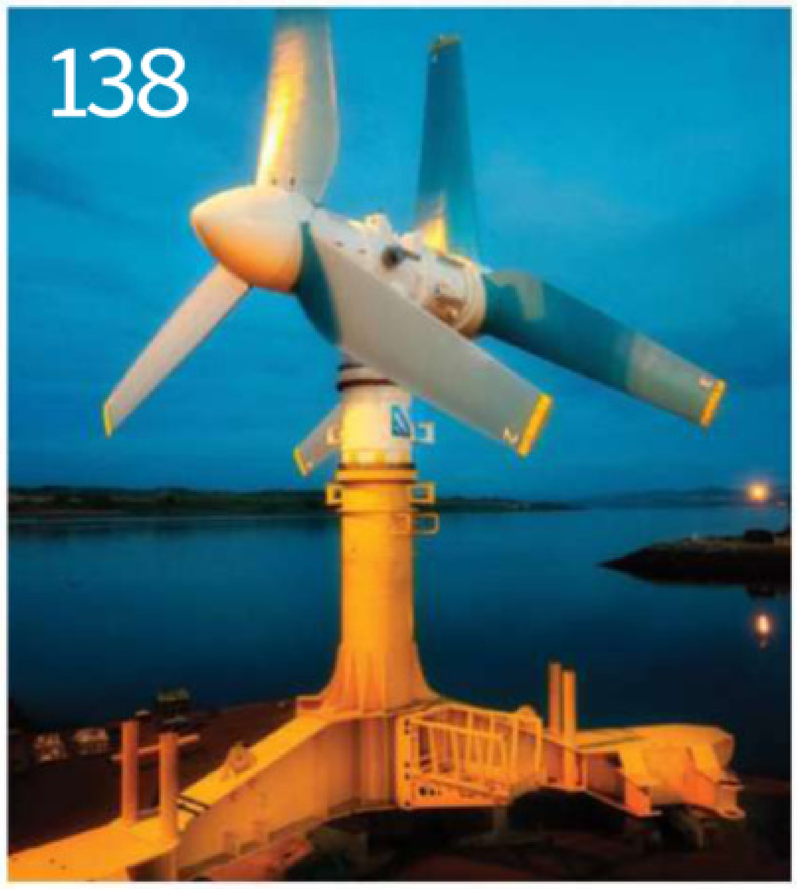

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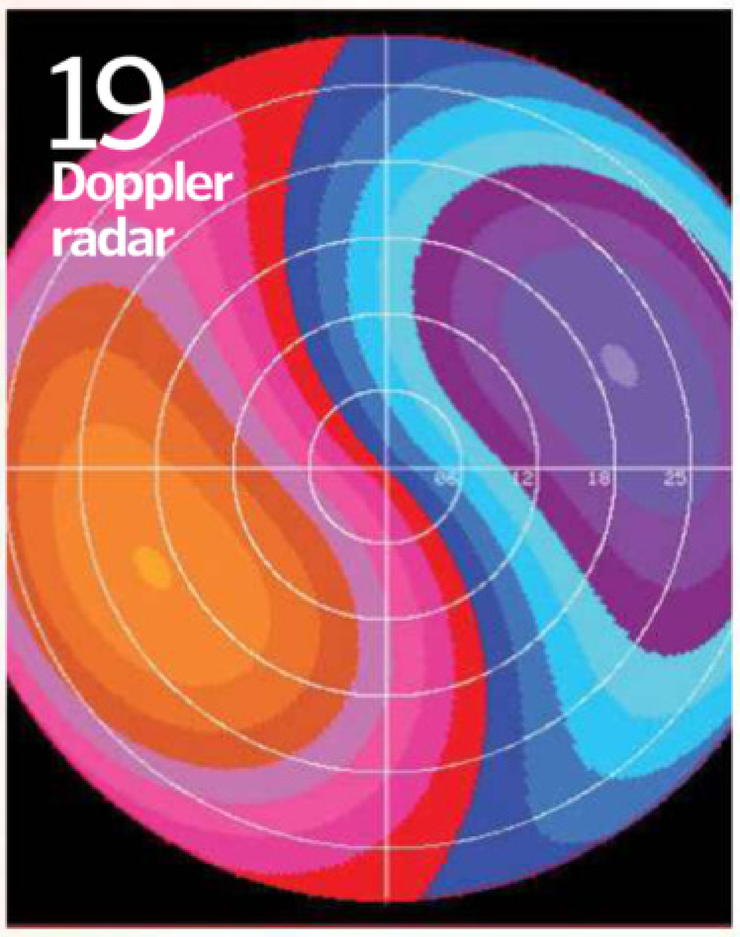

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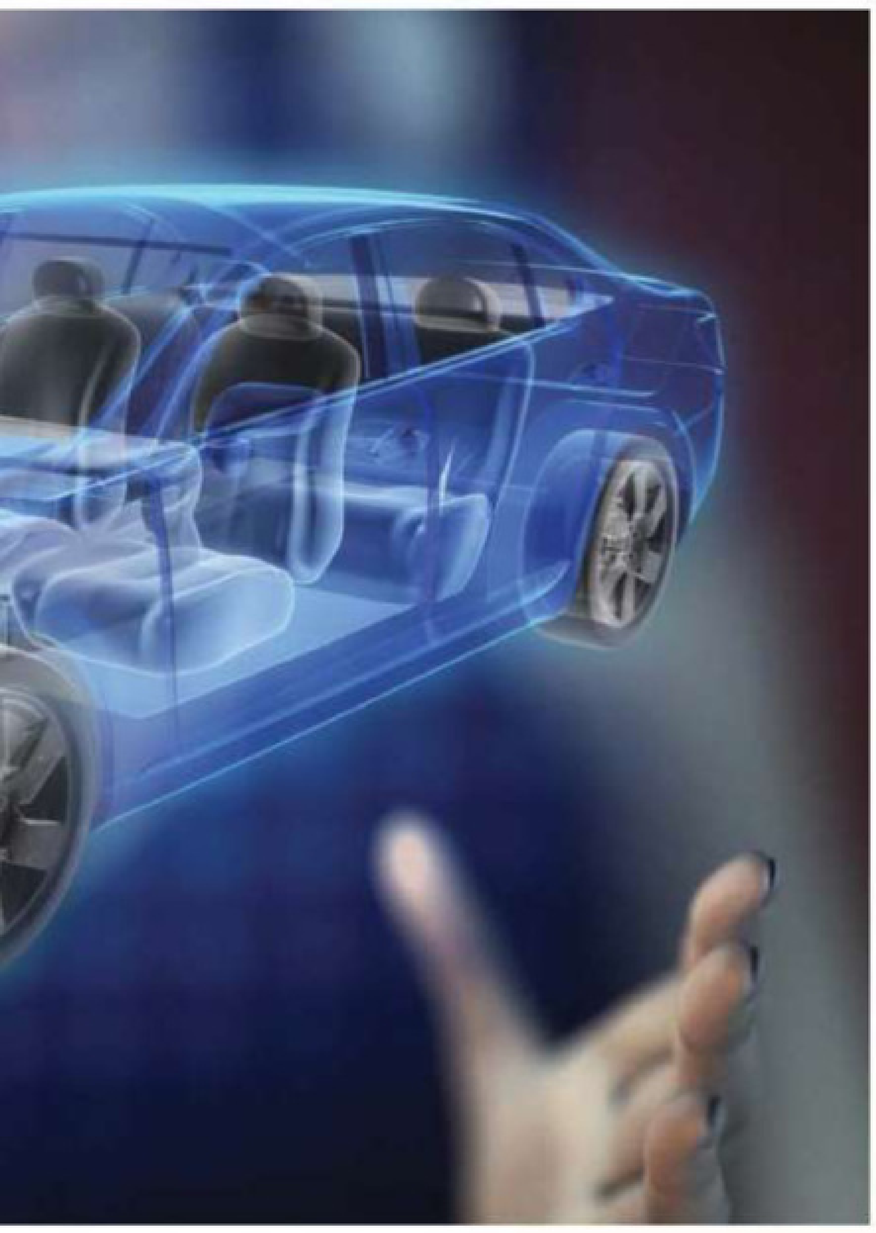

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SPY GADGETS

REVEALED: TOP SECRET TECH

We've all seen spies on the big screen, but few of us have actually interrogated one. When we spoke to former CIA field operative Melissa Boyle Mahle, she revealed what life as a secret agent is really like. "Western countries have this image of what espionage is by watching James Bond movies", she says. "We have this sense of high intrigue in civilised settings, with car chases and explosions. That's not espionage; espionage is much better than that." As for the super-high-tech gadgets? They're (mostly) true. "We share some of the same tools and technologies but it feels different", adds Mahle. "Espionage is chess. You have to outwit your adversaries without them knowing it. A building blowing up is not sneaky."

It seems a true-to-life Bond or Bourne movie would feature much less heat-of-the-moment action. "Operations are sometimes very risky and you don't want to be caught and [get] your agents killed. Espionage in the media gets a bad reputation because they think that it's too easy. It isn't that way. It takes so much planning to get to the right person who has the information you want and how to convince them to give it up. A lot more strategic planning [is involved], a lot fewer car chases!"

When Mahle was at spy school – yes, it really is called that – the Cold War was still raging. Training was geared toward clandestine film photography and if you made a mistake when the images were developed, agents' lives could easily be on the line. The advent of the digital age transformed espionage forever and these days, spies are trained in how to evade technology as much as they are taught how to operate it.

Using real-life spy stories from former agents, this feature will delve into the realm of espionage and reveal the secrets behind the hottest gadgets on the market today.

5 TOP FACTS
BOND GADGETS

Jet pack
1 Fictional super-agent James Bond uses a jet pack in the 1965 film *Thunderball*. It was based on the Bell Rocket Belt that was designed to be used in the US Army.

Tracking device
2 The Aston Martin cars have always been an integral part of the series and in *Goldfinger* an early version of a modern GPS can be seen as Bond tracks down the baddies.

Q robot
3 In *A View to a Kill*, Q comes up with an advanced surveillance robot known as 'Snooper', which can be seen as a precursor to modern observation devices.

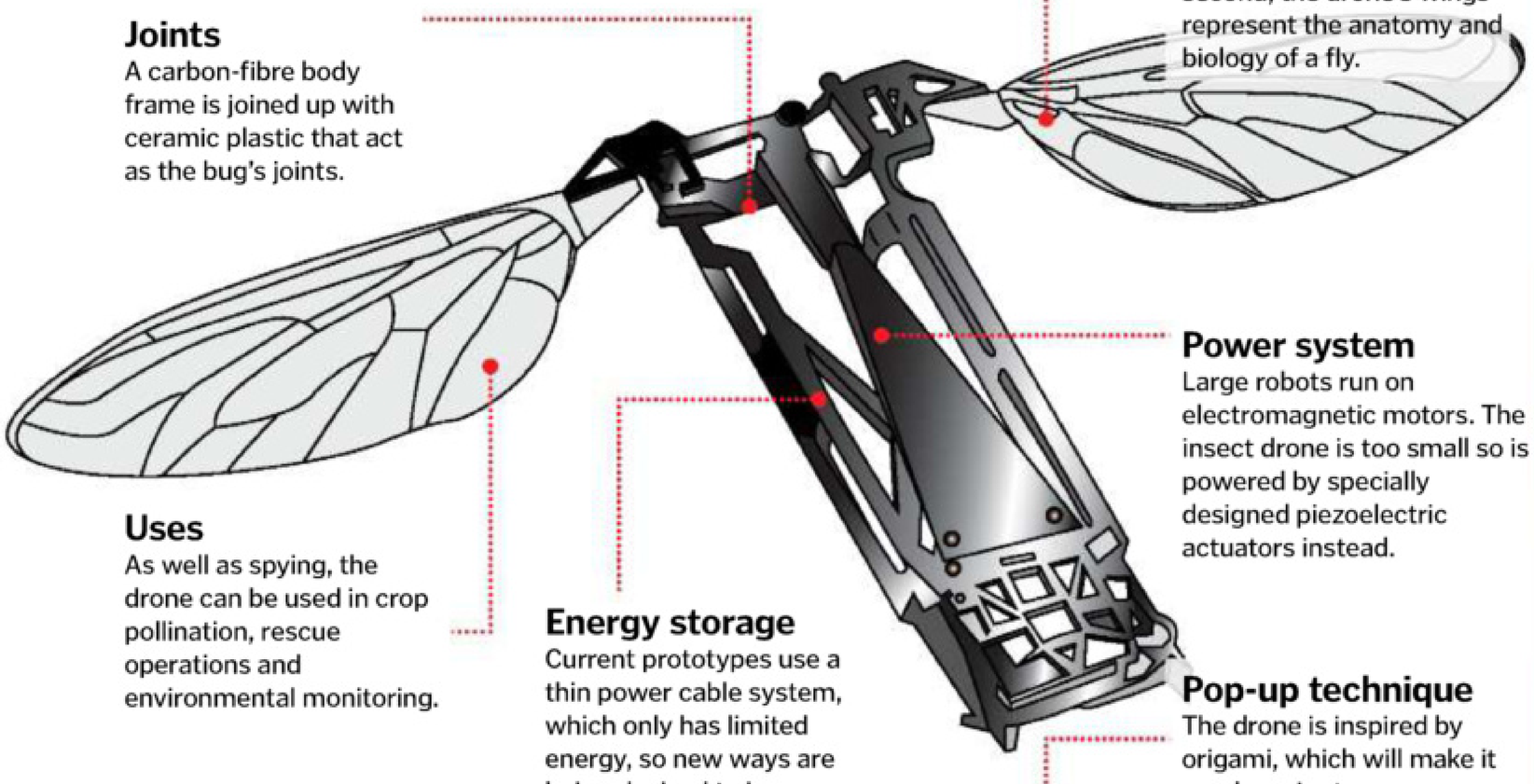
Covert camera
4 In *Moonraker*, a miniature camera, exactly like the ones in real espionage, is used by 007 to take pictures of a villain's nefarious plans.

Wetbike
5 A hybrid of a motorcycle and a jet ski, Bond uses this device in 1977's *The Spy Who Loved Me*, several years before its real-life version hit the market.

DID YOU KNOW? *The highest-grossing spy film ever is 2012's Skyfall, making over $1 billion (£585 million) in cinemas worldwide*

INSECT DRONES

They may look like bugs but they're really highly advanced machines



Joints
A carbon-fibre body frame is joined up with ceramic plastic that act as the bug's joints.

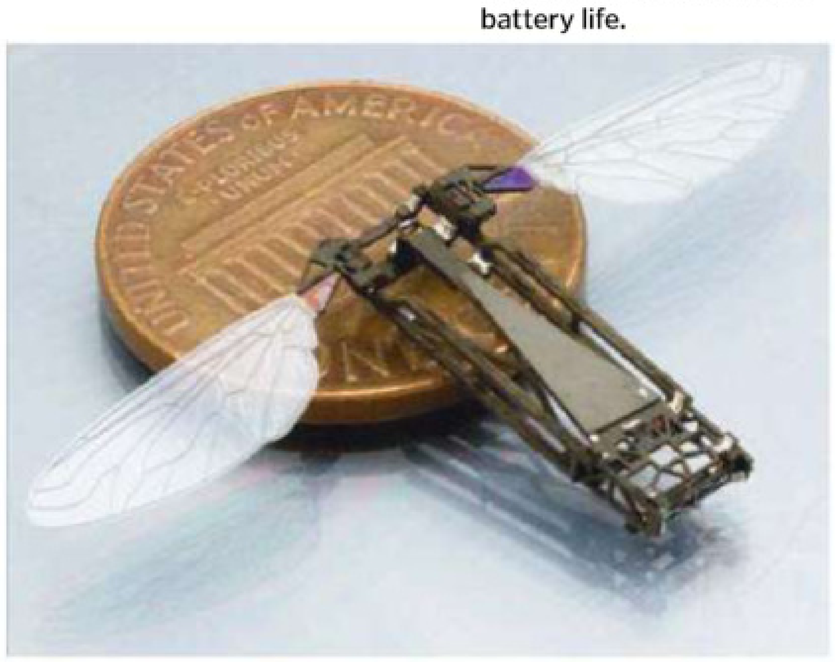
Wings
Flapping 120 times a second, the drone's wings represent the anatomy and biology of a fly.

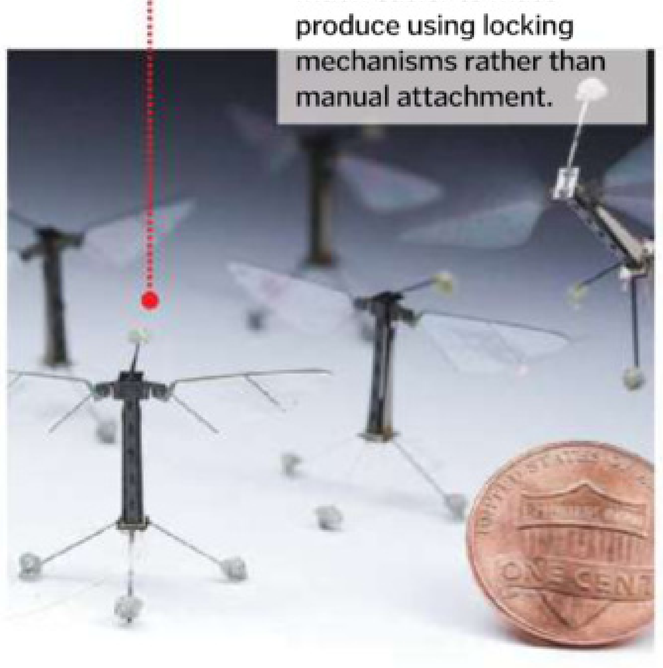
Power system
Large robots run on electromagnetic motors. The insect drone is too small so is powered by specially designed piezoelectric actuators instead.

Uses
As well as spying, the drone can be used in crop pollination, rescue operations and environmental monitoring.

Energy storage
Current prototypes use a thin power cable system, which only has limited energy, so new ways are being devised to increase battery life.

Pop-up technique
The drone is inspired by origami, which will make it much easier to mass-produce using locking mechanisms rather than manual attachment.





With technology progressing so rapidly, it is hardly a surprise that several companies are taking new and innovative approaches to spy gadgetry. One particularly inventive product is the insect drone or 'RoboBee', which is being created with several potential applications in mind, including military surveillance. Disguised as a small insect, one variation of this agile drone has been designed by the Harvard School of Engineering and Applied Sciences. Weighing less than a tenth of a gram and hardly the size of a penny, this tiny robot will be able to access top-secret areas completely undetected. The teeny insect-like flies using wings powered by piezoelectric actuators (deriving the power from pressure) in an electric field. There hasn't been a project similar to this ever before so the majority of the materials used to create the device had to be invented and developed from scratch. The device doesn't travel like conventional human aircraft at all, but instead copies and adopts the flapping of insect wings, adding even further to its bug-like guise. Literally becoming a fly on the wall, swatting pesky insects around with a newspaper could soon literally become integral to your privacy as well as getting rid of the annoying buzz!

Telephone tapping

Learn the secrets of how telephones can be hacked and tracked

Setting up
The first thing a spy will do when wiretapping is to target the main telephone line. They do this by breaking into one of the telephone poles you see on a street. A spy is then free to listen to your calls (or any in the neighbourhood) at will.

Recording the call
Disabling their microphone makes sure they won't give themselves away. They will hook up a recorder to enable repeated listens of the call. Even more sneakily, a bug can be installed in a house to continuously monitor a landline.

Going mobile
Certain software systems can be installed onto a mobile phone. These can monitor calls and text messages. This way if the target has a phone conversation with someone suspicious, you can flick on the device with ease.

CAN YOU SPY A SPY?

Get to know the many different roles of spies

Spying is said to be one of the world's oldest professions, but it is also one of the most dangerous. There have been many attempts to sum up what drives people to become secret agents, including the theory MICE (Money, Ideology, Compromise or Coercion, and Ego or Extortion). For Lindsay Moran, former CIA operative, it was a childhood dream. "I actually sent an old-fashioned cover letter and CV, via snail mail!" she recalls. A few weeks later, she was drafted in for an interview.

After clearing a gruelling assessment period, Moran began training to jump out of aeroplanes with cargo attached to her body, crash cars into barriers at 97 kilometres (60 miles) per hour and travel under an alias. Surprisingly, it was the latter that caused her the most difficulties: "Working under alias is actually pretty stressful and lonely", she says. "I would use a set of alias documents. This entailed spending a lot of time memorising believable details. I was always worried at border crossings and airports – situations where you might be questioned about who you are and what you're doing."

For Mahle, who spent the majority of her career in the Middle East, a fake name was only the beginning. She worked on many of the key challenges to US national security, including running operations against al-Qaeda terrorists, so disguises were essential. "We have many different kinds. It can be low tech with glasses and a wig or very high tech with facemask technology we basically steal from Hollywood. You have to find out about your environment, what the locals wear and how they act. I would often take on the garb of a traditional Arab woman, with black robes, headscarf and sunglasses. Then I could blend in."

Standing up to scrutiny in high-pressure situations is par for the course. "There are different levels of interrogation", she adds. "One is being able to withstand questions into your cover identity, which happens quite frequently when you're operating under a different name. The other extreme is when you are apprehended and accused of being a spy. It's a very hostile environment and I am grateful I was never caught."

1. SNEAKY

Fritz Kolbe

A German working for the Allies, Kolbe gathered and supplied secret documents to the United States containing plans for V1 and V2 rockets.

2. SNEAKIER

Richard Sorge

A Communist spy who infiltrated the Nazi Party, the 'Hero of the Soviet Union' passed on German battle plans to the Soviets.

3. SNEAKIEST

Elyesa Bazna

Codenamed 'Cicero', he was known as the 'spy of the century.' He revealed D-Day invasion plans to the Germans, but they ignored his warnings.

DID YOU KNOW? *The head of MI6 is known as 'C' after the first-ever chief, Mansfield Cumming*

Spy in the city

Discover the roles of secret agents

1 Field agents

A field agent will be entrusted to gather information that cannot be accessed from HQ. Likely to be a double or even a triple agent, they operate behind enemy lines and blend into their surroundings. A risky strategy, a spy must be completely sure their cover will not be blown.
Trusty gadget: Mobile phone tracker or similar.

2 Whistleblowers

A whistleblower will obtain knowledge they believe should be shared with the public, usually within organisations where illegal activity is happening. The media will be alerted to the news and the activity will be investigated. Whistleblowers put themselves at risk when they reveal their identity.
Trusty gadget: A dictation machine.

3 Surveillance squads

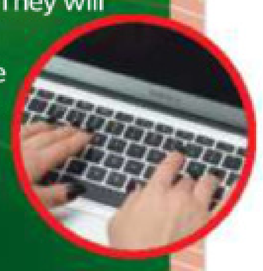
Not always but sometimes located in the 'van with a dish on the roof', surveillance squads work as a team. Keeping a close eye on a group under an inquest, they will gather information that is required for the investigation to go further.
Trusty gadget: Wireless bugging and communication devices.

4 Mole

Also known as a sleeper agent, moles are the most long-term of all spies. Tasked with monitoring an organisation or individual, a mole can spend years in the same place, only responding to missions when assigned. They are trained to be visible but to keep their motives unknown.
Trusty gadget: Covert spy camera.

5 Bureau staff

Most of the legwork is done in the field, but a team is still required back at base. They will gather and assess the information collected by a spy and research the case details. They will also provide backup and deal with issues that can only be solved at HQ.
Trusty gadget: Computer surveillance equipment.



6 Detective

A detective performs the classic spy role. Often posing as a bystander, the detective will investigate criminal activity in the field while remaining completely elusive. They are usually deployed by the police as a prelude to using force and to monitor suspected activity more thoroughly.
Trusty gadget: An audio amplifier.

HIDDEN CAMERAS

These ordinary-looking objects can record your every movement

If there's one modern gadget that has changed the world of espionage in recent years, it's the humble, everyday mobile phone. Today, almost everyone has access to a device that can record high-definition video, capture detailed pictures and track movements, most importantly their own. Mahle reveals that part of every agent's education is learning to spot when you're being watched. "If you're having a clandestine meeting, you need to be very careful that it's done securely", she explains. "Surveillance can come in a variety of different forms, it could be the guy following you as you drive across town or it could be electronic surveillance. Phones are basically GPS [devices]; they are beacons that can track you. We train our officers to be mindful of the physical and technical surveillance they have to defeat in order to keep the operation secure."

This has meant that spy technology has been forced to evolve even further using tiny micro-transmitters and microchips that are almost invisible to the naked eye. Giving a whole new meaning to the game 'eye spy' are glasses that contain built-in cameras and microphones that look exactly like the tiny screws that hold the specs together. The advantage to this is that the camera sees everything the wearer can, and the wide-angle lens ensures that it captures as much of the scene as possible. Gizmos like this are available to purchase online but far from a cheap gimmick. Mahle reveals tech such as this really is part of a spy's essential toolkit: "We use hidden cameras and listening devices, but it depends on how real-time you need the information", Mahle reveals. "If you record something, you will want to go back to it and build up an understanding of your adversary."

"Gadgets won't save you in the moment of the act", she warns. "Technology is widespread now but still, in certain places around the world, capturing a communication device like a camera or a phone can cause security services to start asking questions. As spies, we are very careful about what equipment we use and making sure it does not alert anyone. You don't want your spy tools to give you away."

Spy watch

The combination of a long-life lithium battery plus several gigabytes of memory make a spy watch a worthy purchase. On face value, this timepiece looks like any other, but unknown to the spy's target, they are being filmed by a hidden waterproof camera within the watch's clock. Able to record over an hour's worth of HD footage, the watches are compatible with both Mac and Windows through USB 2.0. They can record video and take still images so any spy can have their scoop saved and sent within minutes.

USB port
Hidden away is a tiny USB port that can be used when the mole returns to base to study the footage.

LED
A small LED lights up to show when the device is recording but it is small enough to not be easily noticed.

Microphone
Sound is just as important as vision, so a microphone is also fitted for when the key information is revealed.

Stop and start
Looking no different to a standard watch, an on/off switch allows for bitesize recordings.

Camera
On the clock face lies a concealed camera that can record video of an unsuspecting individual.

Glasses

Looking no different from normal specs, the glasses are very useful to a spy. With a small wide-angled camera on the frame just above the nose, there is no need for a fiddly viewfinder as snaps can be taken literally wherever you turn your head. Naturally, the lenses are polarised so a target will not suspect a thing. Like the pen and watch, the device can easily be connected via USB to a computer to allow immediate assessment of your findings.

Electronics
As well as a USB and an SD slot, the spyglasses have fast forward and rewind options for repeated listens.

Lenses
The lenses are polarised so an enemy cannot see where you are gazing. Some even have mirrored lenses to see if anyone is following you.

KEY DATES
BRITISH SPYING HISTORY

1909 The Secret Service Bureau is established but later splits, as the MI5 becomes a separate entity from MI6.

1914-1918 The MI5 is expanded to a staff of 844 and catches 65 German spies during the war.

1942 The MI5 contributed to the war effort; including helping keep Gibraltar an Allied territory.

1984 A counter-terrorism branch is set up in the wake of threats from the IRA and Gaddafi's Libya.

2006 'Operation Overt' is undertaken to defend against al-Qaeda suicide bombers.

DID YOU KNOW? *In the Cold War, the CIA developed 'Acoustic Kitty', a programme to use cats as spies*

Night-vision goggles

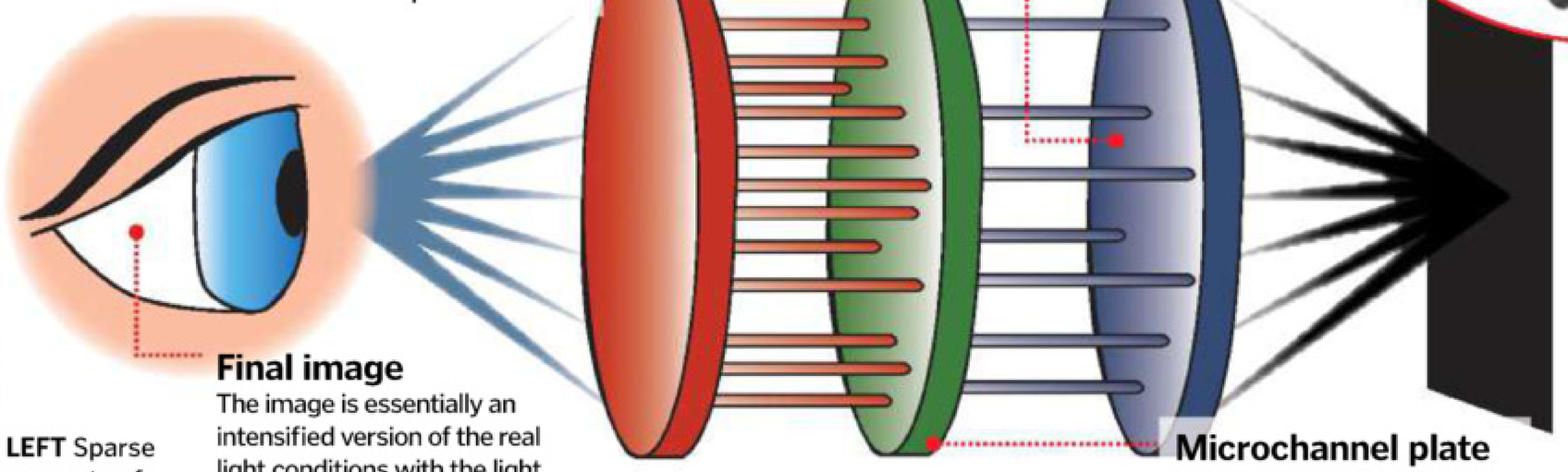
Another spy movie classic that works in real espionage, most night vision goggles can work up to 180 metres (590 feet) away on a clear night. The goggles function in two ways: low-light and thermal imaging. The first collects the sparse light from the lower part of infrared spectrum, amplifies it and creates the image. The second does the opposite by using the top part of the infrared spectrum to detect the heat emitted by people, animals and objects.

LEFT Sparse amounts of light are amplified and enhanced

Ninox Armasight night-vision goggles

Photocathode
This releases the electrons into the phosphor screen. Older devices used to employ three cathodes but now one made out of gallium arsenide can handle the whole process.

Phosphor screen
The electrons in the goggles hit this screen and change into visible glowing light. Different types of screens are available for a varied performance.



Final image
The image is essentially an intensified version of the real light conditions with the light amplified. Some modern devices send out their own infrared beam to use as a light source.

Microchannel plate
This plate helps increase the gain (power) of the goggles as well as the resolution of the intensified image.

Microphones
As well as logging what secrets you hear, the microphone is perfectly positioned to record anything the wearer comments on.

Video recorder
If HQ isn't available, the specs can be plugged into a portable body-worn covert video recorder for instant analysis.

Camera
Placed just above the bridge of the nose, a wide-angle lens records exactly what you can see in front of you.

Spy pen

The ultimate tool for office-desk surveillance, the spy pen can find out just who's been stealing your stationary. Able to capture video and audio, the pen can record HD-quality footage. Extremely simple to use, it has a high amount of storage and a long battery life. The pen could prove invaluable for an undercover spy with the inconspicuous nature of a biro, meaning it is a safe option for espionage missions. The pen comes complete with a USB cable and micro-SD card slot so you can review the footage afterward.

Operation and reset button
The camera begins rolling with a press of the switch at the top of the pen and can be halted at any time with another click.

Camera
The camera itself is located here and uses a tiny lens to capture all the activity a spy will need to take back to HQ.

Pen
Perhaps best of all, you can still put pen to paper like a normal biro, further concealing the gadget's true purpose.

MIC
Next to the lens is the microphone, which can record and uncover top-secret information.

USB and card
When you have gathered your recordings, the spy pen uses a card slot or a USB connection so you can review your findings.

PROTECTING SECRETS

Is high tech always best?

Spy technology is so advanced that it forces you to question even the most mundane objects. Moran revealed that even her notepad wasn't all it seemed. "I had water-soluble paper for the possibility that we were caught," she tells us. "I also had some nifty secret compartments. Sometimes, going back to basics can work just as well, because the technology can't fail you."

Mahle adds that fake rocks, empty soda cans and even dead rats are relied upon. "In high-threat and high-risk environments, we will communicate using 'dead-drops'", she explains. "This is a trade craft where we will hide communications in a concealment device and put down the item in a predetermined location for an agent to come by at a later time to pick it up. It'slow tech but also very secure."

Indeed, the switch to digital has created as many problems as it has solved. Mahle explains: "As technology changes, it presents new challenges to how we operate. It used to be easy to cross international borders but biometrics have made this increasingly difficult. Ultimately, it comes down to the agent and the operator. Whether you use high-tech or low-tech gadgetry, it's people who matter."

Global Positioning Systems

Approximately 30 satellites orbit the Earth to make the GPS system function. Originally a military invention, the GPS is now used in cars and other transportation systems across the globe. The devices work by using a method known as trilateration. The GPS receives a set of signals from three separate satellites and uses this information to plot its coordinates and destination. Spies can use special 'GPS trackers' – like the ones you saw in *Breaking Bad* – to attach to transport and even people to stay on their tail.

Internet encryption

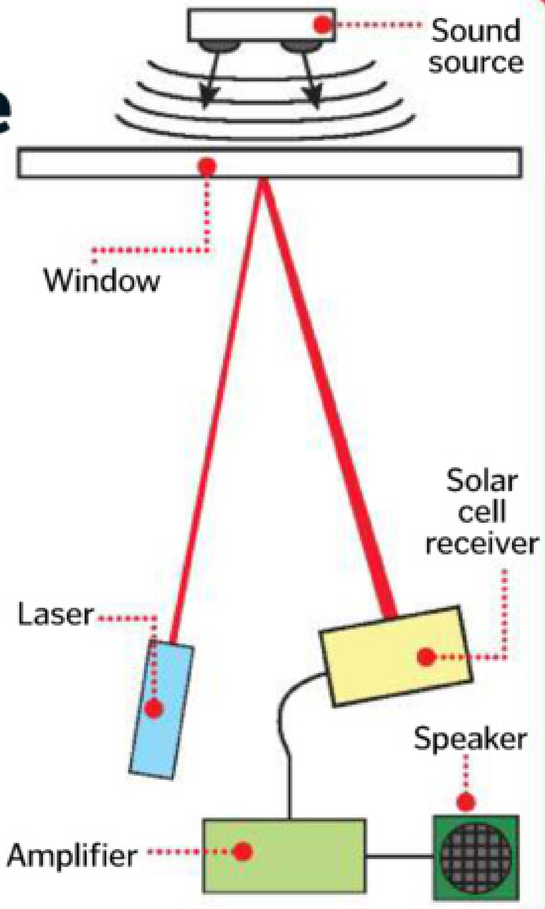
Encryption is the scrambling of data into a code only certain people can read. The system has been used throughout history to send and receive messages and is used today for much the same purpose. Perhaps the most important encryption machine in history was the Enigma used in World War II by Nazi Germany. Encryption is designed to be hard to crack. For example, it is used to hide your card details online. For spies, encryption involves advanced mathematics that jumbles up long and complex passwords and keys, to protect secret and classified information. It uses a digital key that only specific receivers can decipher. Security systems are constantly tightening up their procedures as hackers get ever-more sophisticated in their methods.

Internet surveillance is widespread in today's digital world

Laser microphone

Laser microphones have been a spying revelation. The device uses a laser beam projected into a building to eavesdrop on conversations. It picks up sound waves in the room and bouncing them back to your position. You can even build your own using a laser pointer and some basic audio equipment.

The laser microphone has its roots in a device created by Russian inventor Léon Theremin, who devised a gadget known as 'The Thing' in 1947. It was given to the USA as a gift disguised as the 'Great Seal of the United States' and hung in the US ambassador's office in Moscow. It was only discovered by the US in 1952.



Satellite

Navigation satellites orbit the Earth at 20,000km (12,430mi) and work with the grounded GPS systems using trilateration.

Transport

The microwave signals are transmitted from the satellites into road vehicles to be used as a spy GPS tracking device.

Receiver

Every GPS is part of the GNSS (Global Navigation Satellite System) network and GSM and GPRS towers help support the system.

Computer Servers

A computer at HQ receives data from the tracking unit and displays it enabling base to see the target's whereabouts.

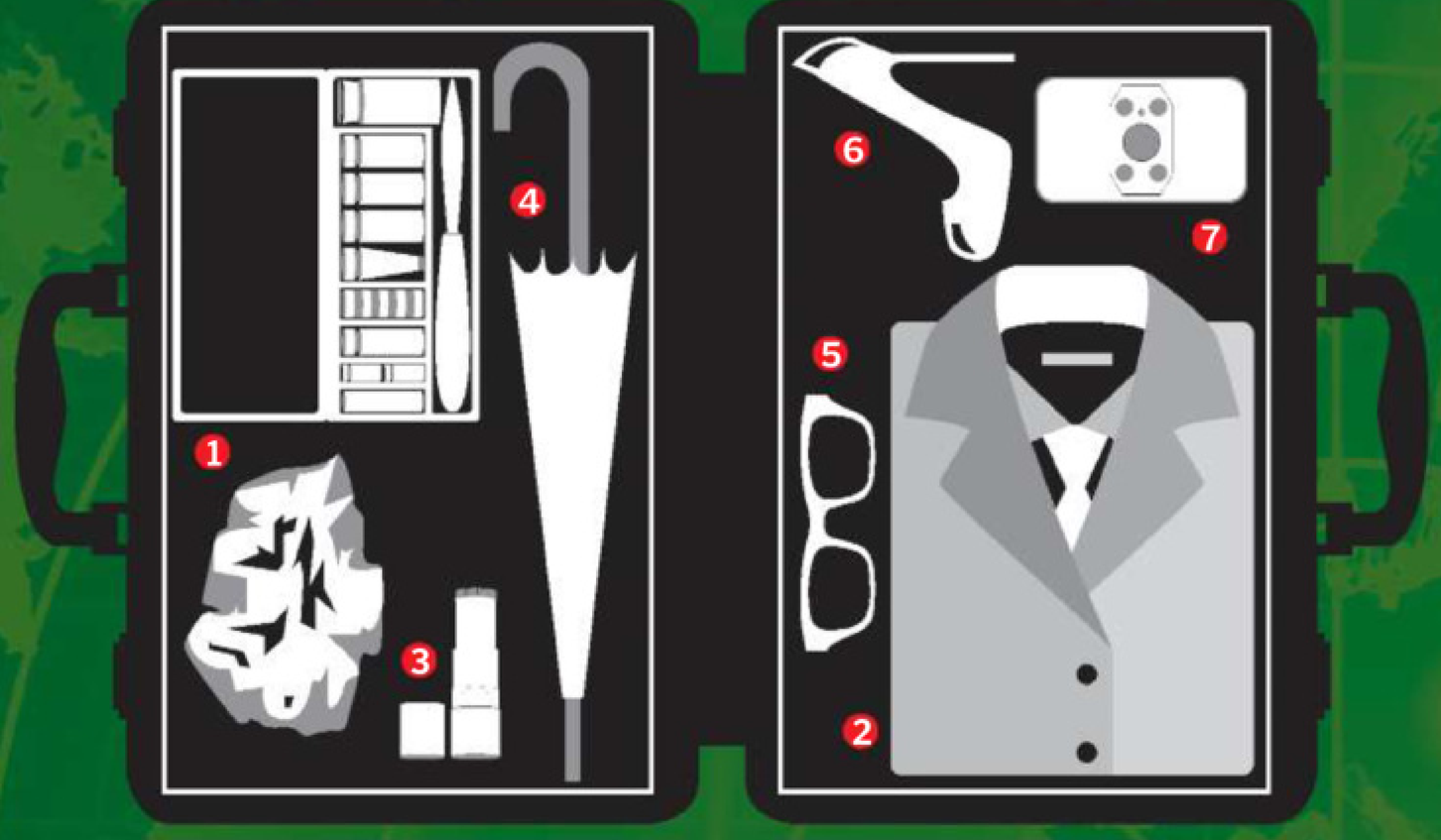
Online

The GPS maps are now online and free for the spy service to track at their leisure.

Retro spy gadgets

Dr Vince Houghton, historian and curator at the International Spy Museum, talks How It Works through the gadgets of yesteryear

Spy gadgets aren't solely limited to modern-day, high-tech gizmos. They played a major part in the Second World War as well as the Cold War, as the superpowers and their respective allies desperately tried to gain an advantage over the other. Below is a selection of the various espionage devices that would have been in a typical spy case of years past.



1 Coal camouflage
Era: World War II

The idea was that you could make an explosive look like an everyday item. This was especially useful in an industrial plant or a train track where you wouldn't give coal a second look.

2 Coat camera
Era: World War II

Designed to take pictures secretly with the spy blending into the environment around them. They were difficult to use, as there was no viewfinder so you had to be pretty skilled at working it.

3 Lipstick pistol
Era: 1960s

Designed to get up close and personal with an enemy, the 'kiss of death' was a low-power single-shot pistol. In couldn't penetrate body armour and you literally had to be next to someone for it to work.

4 Bulgarian Umbrella
Era: 1970s

This brilliantly subtle device was used in the late Cold War by the KGB in London. It fired a gas-fed projectile poison dart that could be carried around the city without being noticed.

5 Cyanide pill glasses
Era: 1970s

These were designed for a spy to take his own life so they wouldn't be interrogated and give away important secrets to the enemy should the worst ever happen and they were captured.

6 Shoe heel transmitter
Era: 1960s

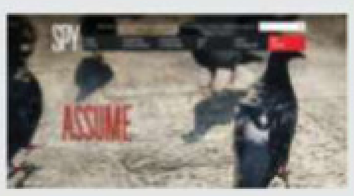
In the era before most everyone had GPS-tracked phones on them, these were attached without the knowledge of the individual wearing them and the person could be tracked wherever they went.

7 Pigeon camera
Era: World War II

Homing pigeons outfitted with tiny cameras were released over military sites to gain information. The photos taken automatically during the flight were developed and interpreted upon the pigeons' return.

Learn more

To discover more exciting spy tech, visit **www.spymuseum.org** where you can also plan a visit!



© Alamy; Bundesarchiv; Night Vision Gear UK; Thinkstock; Ed Crooks; Ian Moores; International Spy Museum; Robert J Wood & Pratheeve Sretharan, Microbiotics lab, Harvard University; Kevin Ma and Pakpong Chirarattananon, Harvard SEAS

Google Glass

Merging the real and virtual worlds together

Computing giant Google has announced that its innovative Google Glass system is now available worldwide. But apart from looking seriously cool, what does it actually do? In short, Google Glass is a new type of smart eyewear or OHMD (optical head-mounted display) that can perform several different tasks, from seeing what you've got left on your shopping list to mapping out the golf course you're currently on.

The spectacle-like device can do all the basic things you'd expect from a modern smart gadget, such as playing music, acting as a compass and measuring the steps on your weekly jog but it also has more advanced features. The party trick of the device could well be its Bone Conduction Transducer, which rests just behind the ear. This transmits sound from the device through the bone of your skull to your inner ear.

Some of the features of Google Glass may be more of a novelty than others, such as recording videos by winking, for instance, but Wi-Fi and Bluetooth connectivity is very useful for checking your social networks or finding out how your favourite football team is getting on during a live match. Google Glass is expected to market at approximately £1,000 ($1,600) on its commercial launch and will originally be available to over-18s only. Despite this, some sources are predicting sales of 21 million units by 2018 so expect to see them almost everywhere in the very near future.

Dissecting Glass

What are these futuristic specs made up of?

Voice command
A transducer next to the ear uses bone conduction to transmit sound through the skull.

Video
The video is displayed and recorded in 720p for HD-quality footage of your daily life.

Photos
The Google Glass's camera can take five-megapixel snaps with an impressive 2528 x 1856 resolution.

Added extras
The glasses contain a three-axis magnetometer, accelerometer and gyroscope for use as a compass, pedometer and coordination respectively.

All weather
The gadget can work rain or shine so you'll never need to buy tiny Google Glass wipers no matter how (un)cool it'll look.

Display
The general display of the Google Glass is 640 x 360 for clear visuals throughout the day.

"The spectacle-like device can do all the basic things you'd expect from a modern smart gadget [...] but it also has more advanced features"

The Google Glass video can record footage that will look exactly how you saw it first time round

Glass rivals

The new kids on the block

All the fanfare has been about the Google Glass but there are actually many other companies aiming to develop the ideal smart eyewear product. The Samsung Gear Blink is more of an ear computer with a small display in front of one eye, which will include a virtual reality keyboard. Also on the radar is the Sony Smart EyeGlass that will link up to Android phones in a very similar way to Google's device. Away from the major players, some smaller firms are also making inroads into the emerging market. The ChipSiP promises a HD resolution display while the Baidu Eye from China has no screen so will be a long-lasting and simpler alternative to the other products.

© Alamy; Corbis; Google

Doppler radars can be used in a number of devices including speed guns and weather-tracking equipment (inset)

Doppler radars

Learn about the technology that tracks the motion of objects using echoes and the Doppler effect

Radar equipment produces electromagnetic waves, such as microwaves or radio waves. The waves hit the target and are reflected back towards the detector. In a similar way to echolocation in bats, the time it takes for the wave to reflect back can be used to determine the distance.

By sending out waves of a known frequency, the radar can also be used to determine the velocity of the target. When a police car drives past, the siren sounds high-pitched as it heads towards you, and rapidly changes to a lower pitch once it has zoomed past – this is known as the Doppler effect. If the radar target is moving towards the detector the frequency of the waves arriving at the detector is increased, and if the target is moving away, the frequency is decreased, allowing its velocity to be calculated.

Doppler radar has a variety of applications. The police use handheld radar guns to determine the speed of passing vehicles, while military planes contain pulse radars for targeting. Large-scale Doppler radar is also used to scan the atmosphere to follow aircraft, or to track and predict the weather.

Electronic cigarettes

How do eCigarettes create vapour that mimics tobacco smoke and are they harmful?

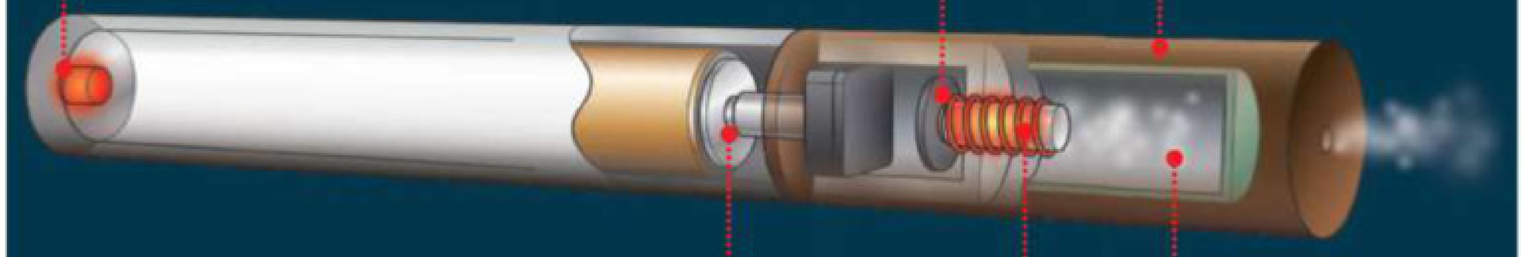
Battery-powered cigarettes convert dissolved nicotine concentrate into vapour, which can then be inhaled without many of the toxic by-products associated with burning tobacco.

The electronic cigarette has three basic components: a chamber, an atomiser and a battery. The chamber contains nicotine and flavourings in a carrier liquid, such as propylene glycol. A wick, made from metal mesh or silica, draws the liquid into the atomiser, where it is heated by a battery-powered coil until it vaporises. The vapour is then inhaled and exhaled like tobacco smoke.

Electronic cigarettes are designed to simulate the feel, taste and nicotine hit of cigarettes, but their safety is debated. In many countries their manufacture and sale is unregulated, resulting in variation in their chemical contents. Their usefulness as nicotine replacement therapy is also largely unknown and the World Health Organization does not condone their use.

No smoke, no mirrors

The technology that powers smoke-free eCigarettes is surprisingly simple



LED
Many electronic cigarettes have a light at the end to simulate glowing embers.

Sensor
Some eCigarettes have a pressure sensor to detect when the user draws on the mouthpiece, powering up the coil; others use a button.

Cartridge
A reservoir contains the liquid and delivers it to the atomiser. A sponge is often used to hold it in place.

Battery
Rechargeable eCigarettes use a lithium-ion battery, which supplies power to the heating coil.

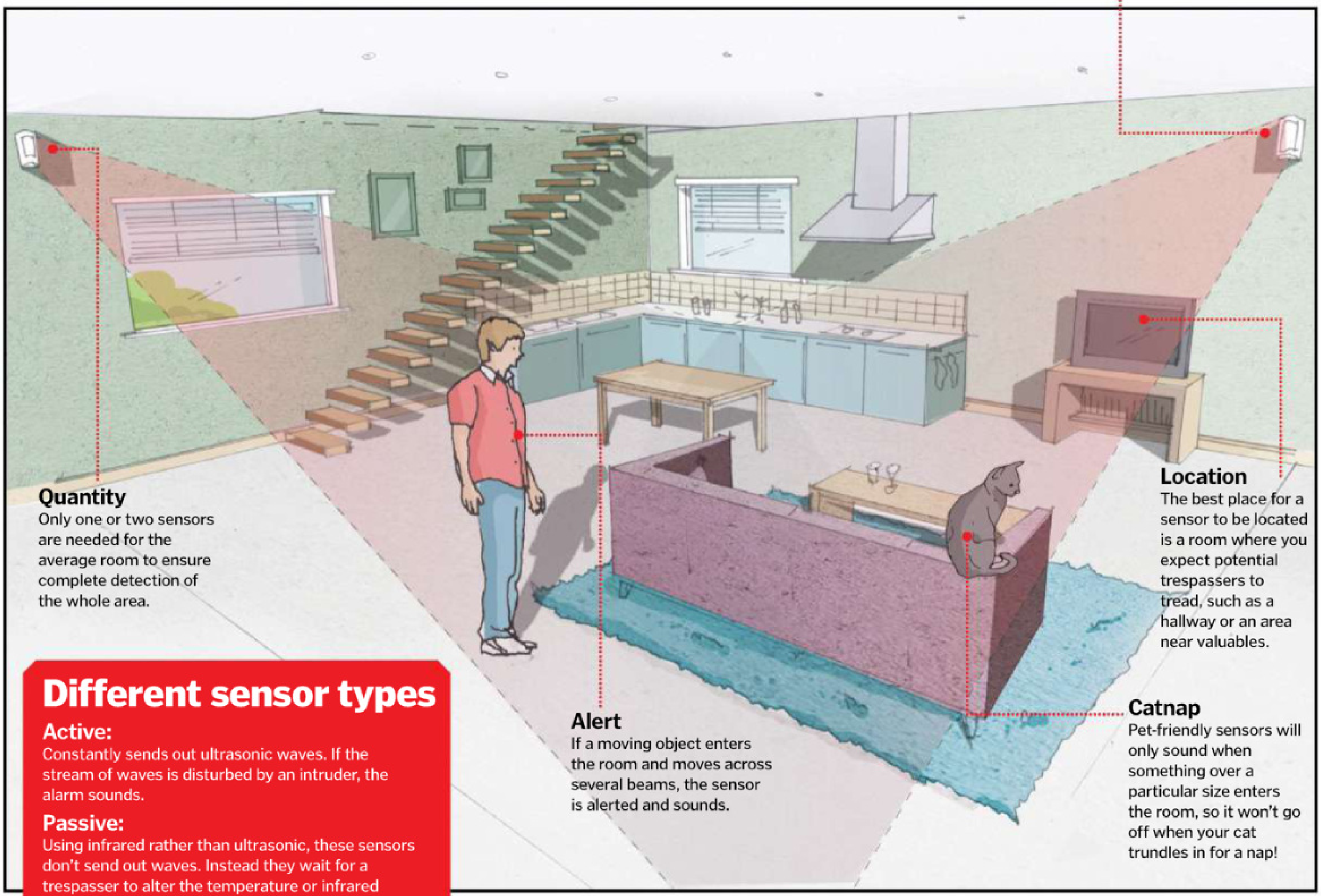
Atomiser
The liquid is drawn up by a wick and vaporised by a heating coil, producing a mist that resembles cigarette smoke.

Liquid
Propylene glycol (PG), vegetable glycerine and/or polyethylene glycol carry the nicotine and various flavourings.

© Thinkstock

World in motion

The inner workings of motion sensors explained



Active and passive
'Active' detectors use microwaves and ultrasound while infrared is the preferred wavelength in 'passive' devices.

Quantity
Only one or two sensors are needed for the average room to ensure complete detection of the whole area.

Alert
If a moving object enters the room and moves across several beams, the sensor is alerted and sounds.

Location
The best place for a sensor to be located is a room where you expect potential trespassers to tread, such as a hallway or an area near valuables.

Catnap
Pet-friendly sensors will only sound when something over a particular size enters the room, so it won't go off when your cat trundles in for a nap!

Different sensor types

Active:
Constantly sends out ultrasonic waves. If the stream of waves is disturbed by an intruder, the alarm sounds.

Passive:
Using infrared rather than ultrasonic, these sensors don't send out waves. Instead they wait for a trespasser to alter the temperature or infrared energy of the area to make them sound.

AR Drone 2.0

The latest generation of personal drones

Until recently, the drone world was the domain of the world's military, but now we are able to use them as our own personal moviemakers. The AR Drone 2.0 is a 380-gram (13.4-ounce) carbon-fibre video drone. Using an app you can download onto your Android or Apple device, you pilot the drone by tilting your smartphone or tablet, guided by the on-board camera.

The HD camera records at 720p, which it sends straight to the smartphone or tablet you're using to pilot the drone. If you really want to channel your inner Tarantino, you can set the drone to Director Mode. This sends it into semi-autonomous mode, providing a stable pan or crane shot. Footage remains steady thanks to a pressure sensor that keeps the drone upright regardless of altitude and winds up to 15 kilometres (nine miles) per hour.

"At certain frequencies it acts as a sort of musak that can calm people and help prevent drunken brawls"

Sonic weapons

Cover your ears and discover how sound can be used to stop riots and brawls

To disperse crowds and prevent rioting, various forms of non-lethal weapons (NLW) are used. Among these, interestingly, is sound. Known as an acoustic or sonic weapon, infrasound (super-low frequency) and ultrasound (super-high frequency) greatly affect human ears. They can disorientate a target and have psychological effects as well as physical effects of nausea and damage to blood vessels.

Ultrasound can be increased to 120 decibels (the same volume as a jumbo jet taking off), which is considered the human pain threshold. In contrast, infrasound feels like a damaging vibration or pressure wave, as it's at a frequency too low for humans to hear. When exposed to high levels of sound, the influx of energy has a painful effect on the body.

As well as huge decibels of volume, the variations in frequency can also cause damage. For instance, an infrasound of seven or eight Hertz can rupture blood vessels. Certain types of sound within the frequencies we are able to hear also have psychological effects, acting a sort of musak that can calm people and helps prevent drunken brawls.

In New York City, piezoelectric loudspeakers are used by the NYPD. They focus sound waves in a particular direction to control large crowds. Known as Long Range Acoustic Devices (LRAD), some types can reach a maximum of 162dB. Another device is the sonic bullet. Made by inventor Woody Norris, it sends a beam of up to 145dB into its target. Prototypes are already in production to be used in the US Army to help enforce safety areas in warzones.

Long Range Acoustic Devices

Discover how this breakthrough device uses sound to its advantage

The LRAD Corporation's 100X can reach volumes of 137dB while the 1000X can reach a hefty 153dB

Output
The LRAD 100X is powered by a standard AC source or a rechargeable lithium battery. Its volume can reach up to 137dB.

Portability
Weighing in at a paltry 6.8kg (15lb), the 100X can easily be taken from location to location.

Range
Four to six times louder than all other systems of its size, the 100X has a range of over 600m (1,969ft) and can overcome background noise at 250m (820ft).

Materials
The 100X is made from water- and impact-resistant plastic and aluminium so it is tough enough to withstand riots and combat situations.

Uses
The system can be used for a variety of situations including law enforcement, border security, communication and even wildlife control.

© LRAD Corporation; Thinkstock; Alamy

Perfect match

Match the animal with the power of their sound (measured in decibels)

218dB

110dB

230dB

Lion

Sperm whale

Tiger pistol shrimp

Answers: 218dB = tiger pistol shrimp; 110dB = lion; 230dB = sperm whale

Digital classrooms

From virtual lessons to interactive whiteboards, discover how new technology is revolutionising the way we learn

Technology is now at the heart of many classrooms, providing students with access to a whole new way of learning. Using digital technologies, combined with the internet, school is becoming a multimedia experience. Indeed, in 2012 there were 1.5 million iPads in use in education, as well as over 20,000 educational apps.

Of course, the internet has brought a huge resource to the digital classroom, granting instant access to a wealth of online information and educational tools. Many universities are uploading free materials to massive open online courses (or MOOCs) like iTunes U and Coursera, providing global access to free world-class education. Classrooms and labs are now also often equipped with microphones, speakers and webcams, opening up opportunities for collaborations across the globe.

Access to these digital educational resources is no longer limited to a single, rarely used computer in the corner; in fact, interactive whiteboards are now the focal point of many classrooms. A stylus, pen or finger is used to interact with a whiteboard, on which an image of the computer screen is projected. The user's movements are detected by the board and relayed back to the computer, allowing the user to write and draw on the screen (see 'Next-gen whiteboards' boxout for more detail).

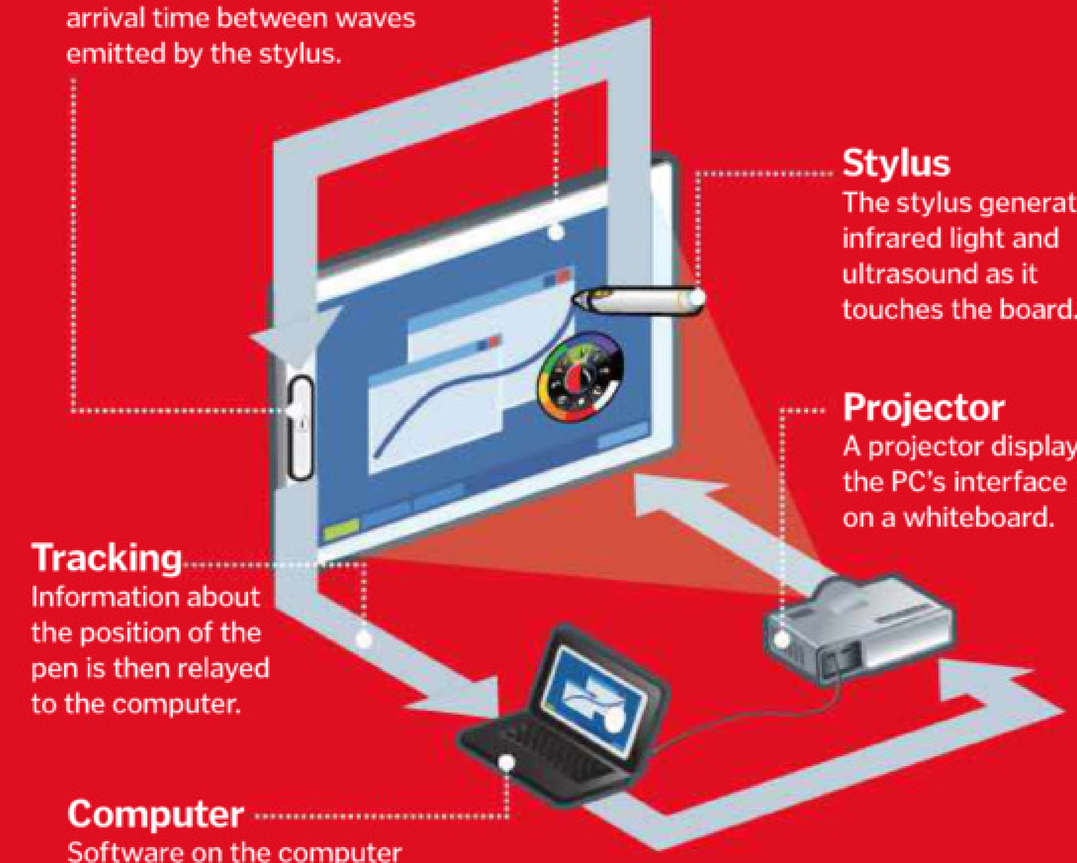
The interactive whiteboard is so much more than a digital chalkboard though. The pen-style interface means that many models come with bespoke software capable of handwriting recognition, converting everything that is written on the board into a digital archive. There are also programs available that allow anything drawn on the screen to be printed, recorded, shared and rewatched later. This has opened up possibilities for remote learning, allowing students unable to attend the physical classroom to still participate virtually.

What technology makes a whiteboard interactive?

Interactive whiteboards use a variety of technologies to provide the interface between user and screen. Infrared whiteboards use infrared wavelengths directed across the surface of the board. When a pen touches the board, it interferes with the light, allowing the point of contact to be calculated. Similarly, ultrasound whiteboards use the deflection of ultrasound waves to detect a stylus's movements.

Some whiteboards, like the eBeam made by Luidia pictured here, do not actually need an electronic board at all, but use a detector which is mounted to the side of a traditional whiteboard.

The eBeam system actually combines both infrared and ultrasound. By using the two together, differences in the time taken for the waves of light and sound to travel across the board enable the location and direction of the pen to be pinpointed. This works in a similar way to predicting the distance of a storm based on the time delay between seeing the lightning strike and then hearing the thunder.



Receiver
The receiver (on the board) detects the difference in arrival time between waves emitted by the stylus.

Infrared and ultrasound
Light and sound travel at different speeds – by determining the time delay between each, the distance to the source can be calculated.

Stylus
The stylus generates infrared light and ultrasound as it touches the board.

Projector
A projector displays the PC's interface on a whiteboard.

Tracking
Information about the position of the pen is then relayed to the computer.

Computer
Software on the computer treats the receiver as if it were a mouse, using the information to interact with the desktop.

KEY DATES
PCs IN SCHOOL

1970s
Pocket calculators become affordable, with many students starting to use them to help with sums.

1984
There's one computer for every 92 students in the US, such as early educational PCs like the Plato.

1991
The first interactive whiteboard is introduced by SMART; it takes several years to go mainstream.

2006
Cheap, durable laptops like the XO-1 are built so kids across the developing world have access to computers.

2010
Many schools begin using Apple iPads for educational games, video, apps and web browsing.

DID YOU KNOW? *In English primary schools, there are currently around 1.8 students to every computer*

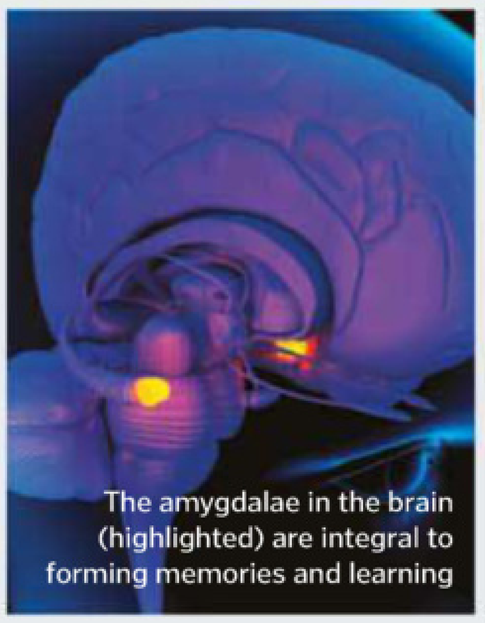
Dusty chalk and squeaky pens are now very much things of the past

How do we learn digitally?

As we learn, connections between neurons in the brain are reinforced; the more they are used, the stronger they become and the more easily we are able to recall the information.

Digital classrooms provide an engaging environment to reinforce memory. Different people find that they learn more easily in some ways than others – some preferring to watch, others preferring to interact, etc. Digital classrooms are able to offer tailored ways of learning, appealing to a wide range of preferences, and enabling classes to be adapted to individual students. One of the major advantages is that technology makes learning more fun, keeping pupils engaged for longer and providing memorable experiences to really help the knowledge stick.

One technique being increasingly employed to enhance learning through technology is 'gamification' – essentially turning learning into a game. The best educational games allow the student to learn without even realising it. Many of these games also include virtual rewards and leaderboards for an extra incentive.



The amygdalae in the brain (highlighted) are integral to forming memories and learning

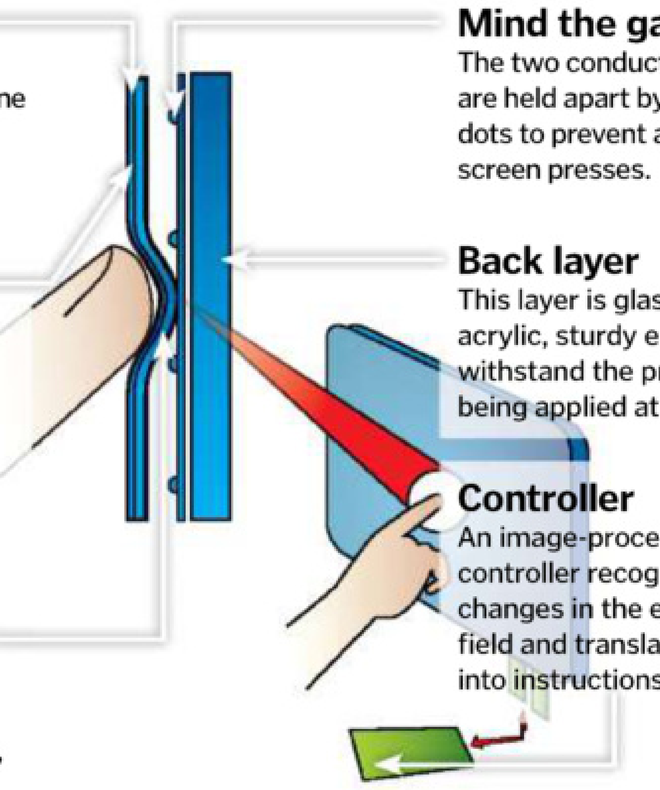
© eBeam; SPL; Mike McGregor

Touchscreen interaction

This tactile technology comes in two main flavours – resistive and capacitive – but what are the key differences between them?

Resistive screen

Tougher, cheaper and simpler, resistive touchscreens are widely used in our everyday devices



Top layer
This is typically made of scratch-resistant polyethylene (PET) which is designed to flex slightly under pressure.

Mind the gap
The two conductive layers are held apart by spacer dots to prevent accidental screen presses.

Back layer
This layer is glass or acrylic, sturdy enough to withstand the pressure being applied at the front.

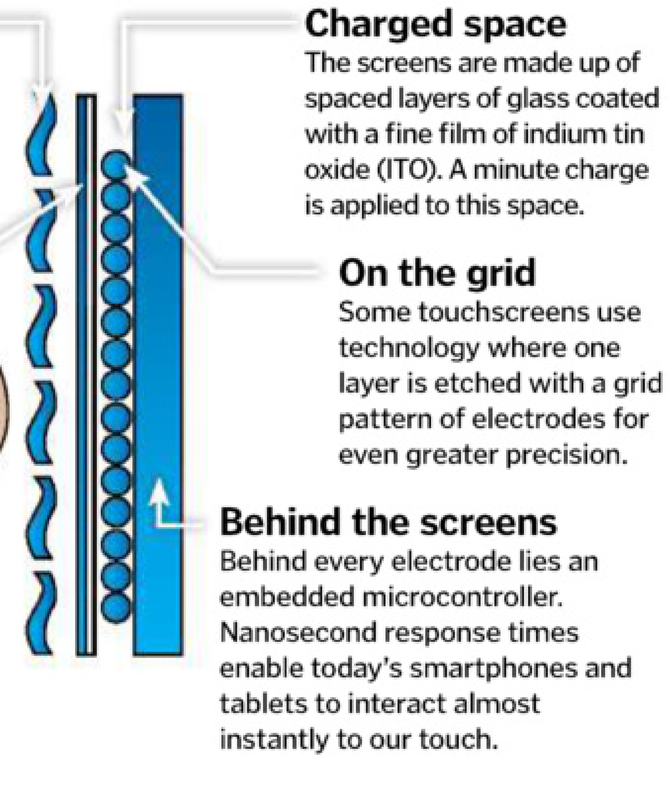
Resistance
Resistive touchscreens are made of several layers, each with a conductive indium tin oxide (ITO) coating. A current passed between these layers creates electrical resistance.

Controller
An image-processing controller recognises changes in the electrical field and translates these into instructions.

Push technology
When pressed with a finger or stylus, the two ITO coatings below meet, completing a circuit.

Capacitive screen

More accurate and much more versatile capacitive has to be today's touchscreen of choice



Invisible field
Capacitive touchscreens monitor minute changes in the local electrostatic field being created just above the surface.

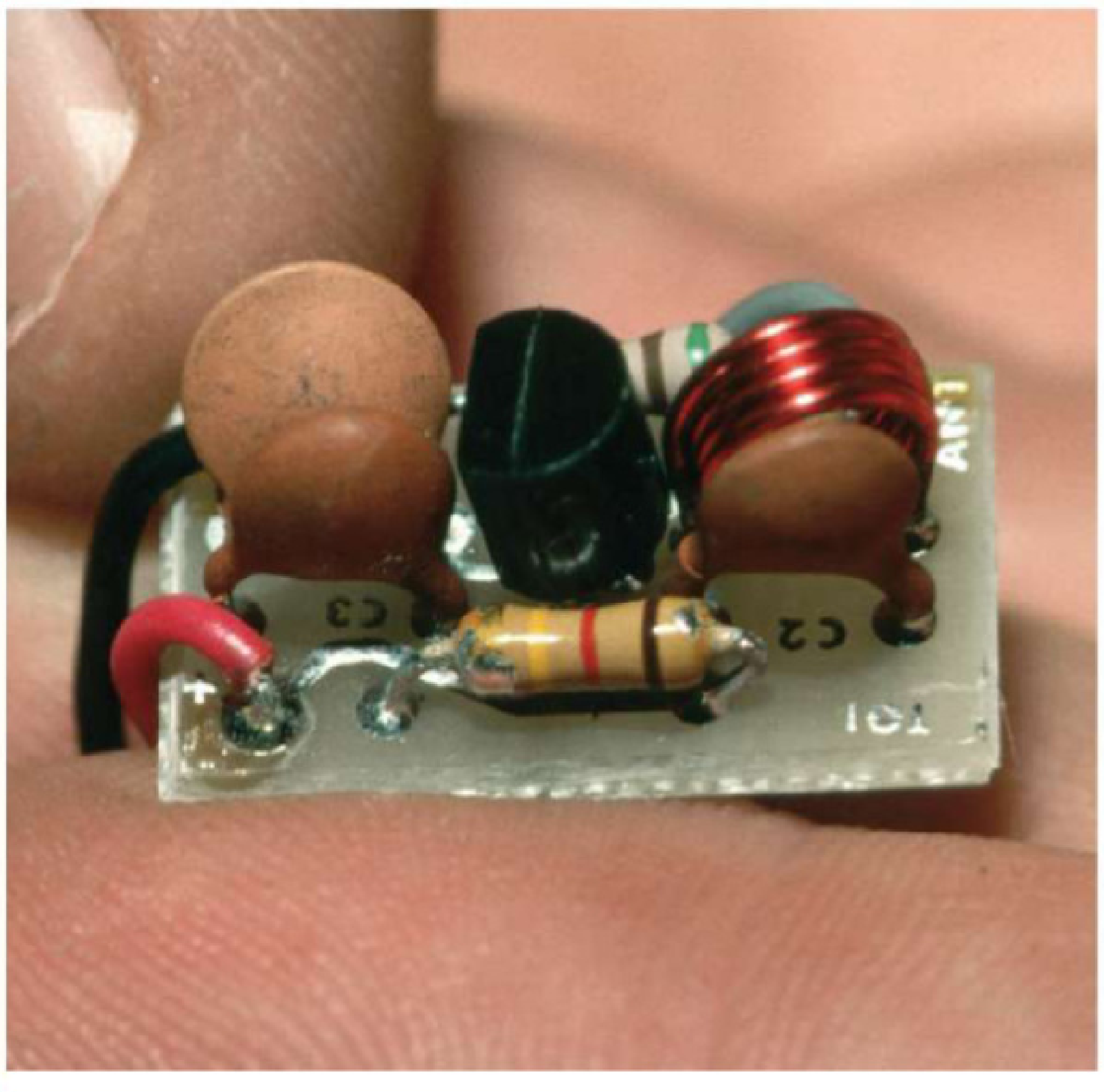
Charged space
The screens are made up of spaced layers of glass coated with a fine film of indium tin oxide (ITO). A minute charge is applied to this space.

Glass layer
Touching the top glass creates conductivity between your skin and the charged space beneath.

On the grid
Some touchscreens use technology where one layer is etched with a grid pattern of electrodes for even greater precision.

Human touch
Capacitive touchscreens respond to the unique conductive qualities of the skin. They rarely work with gloves (unless special capacitive ones).

Behind the screens
Behind every electrode lies an embedded microcontroller. Nanosecond response times enable today's smartphones and tablets to interact almost instantly to our touch.



Phone bugs explained

Learn how modern listening devices eavesdrop on our conversations

Traditionally bugs have two main components: a microphone to capture the audio and a radio transmitter to relay the conversation to the listener. The microphone is activated when sound reaches a threshold level, or when a radio signal of the correct frequency is sent to the device.

Newer bugging techniques tend to take advantage of modern mobile phone and laser technology. GSM (Global System for Mobile Communications) audio bugs contain a SIM card. When called, the bug will automatically – and silently – answer, and pass on audio to the listener's phone. Laser listening devices, on the other hand, do not require a microphone at all, but detect the changes in vibration of objects as sound waves hit them. A laser aimed at a particular reflective surface, like a window, can detect minute changes in the vibration caused by shifts in air pressure as people talk. Laser bugs require the listener to be in line of sight of the target, but unlike microphone-based devices, no one needs to break into a property to plant the bug.

© Corbis

Electron guns

Far from a weapon, these guns are an important part of everyday electricals

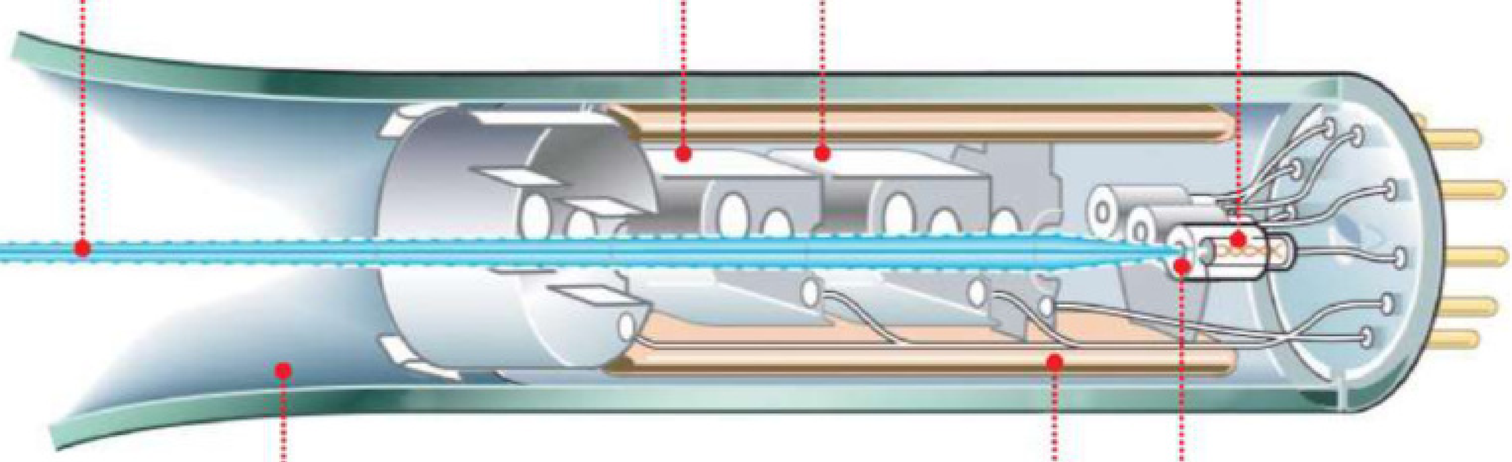
Electron guns are a very versatile electrical component. They are essential to a number of devices, from 3D printers and welders to the large synchrotron at the Diamond Light Source in the UK and the electric systems of Kimball Physics in the US. But how do they work? It's all down to kinetic energy and electrical currents. When installed in an electrical device's vacuum tube, the gun turns electrons and ions into usable beams of energy by releasing them from their metal source (cathode). This process is known as thermionic emission.

Inside the gun there is a small filament that heats the cathode, which makes it release a stream of electrons. The electrons accelerate rapidly and the resulting beam is pulled toward the neighbouring anode, which is positively charged. There are small holes in the anode which allow some electrons to pass through, so a concentrated beam then continues onward within the device. JJ Thomson discovered the electron using this concept in 1897 after conducting experiments with cathode rays and studying their uses.

There are two main types of electron gun: thermionic and field emission. The former are much more common and work at a high temperature. Field emissions have less heat but a higher brightness and electric field. Additionally, 'flood guns' are used to scatter the beam over a wider area.

Naked gun

Inside the inner workings of an electron gun



Electron beam
Now a strong and usable ray of light, the electron beam can exit the gun to work in the rest of the device.

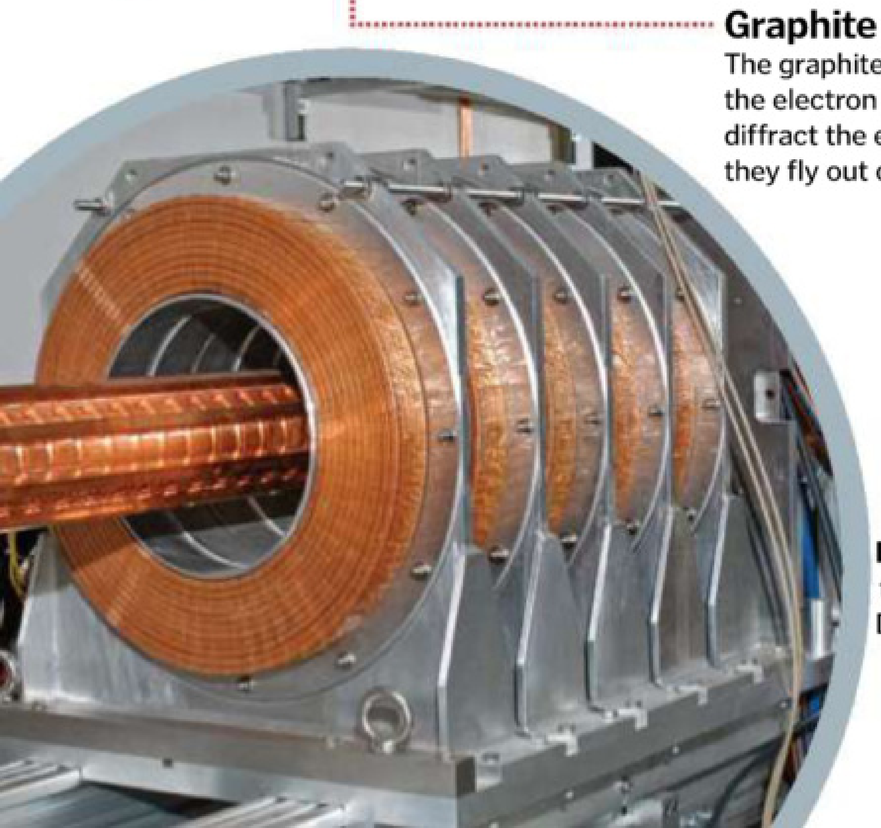
Anode
Made up of two parts, the anodes accelerate and focus the electrons to make a beam.

Heater
Working in unison with the cathode, the heater's hot filament begins the whole electron-gun process.

Graphite
The graphite foil coating of the electron gun helps diffract the electrons as they fly out of the gun.

Cathode
Warmed by the heater, this is where the electrons are heated and emitted.

Insulator
An insulator is provided within the gun to be used as a charge drainage path for excess energy.



LEFT The electron gun at the Diamond Synchrotron in Didcot, Oxfordshire

Chris Christou working on the Diamond Light Accelerator

Electron expert

We chat to Chris Christou, the head of the radio frequency group at Diamond Light Source, who have a supremely powerful electron gun of their own

How is energy turned into a usable product by the gun?
The key is getting the electrons out of the conductor, which the electrons are bound to. The hard part is controlling the electrons once they have escaped. We heat the metal, which gets the electrons out of the cathode and then pulls them away with a high electric field.

How do they work in TVs and the Diamond synchrotron? These are very different things!
Electron guns are very versatile as the physics behind them is relatively simple. It's just giving energy to an electron to take it away from a bound state. The hard part is controlling the beam after it comes out of the cathode of the gun. At Diamond we have a set of electrodes on the gun, which shape the beam to allow it to be extracted and taken into the linac. Old cathode-ray TVs have something like 10,000 volts to accelerate the beam straight into the screen. So the difference between TVs and us is what we do with the beam is after it's been generated.

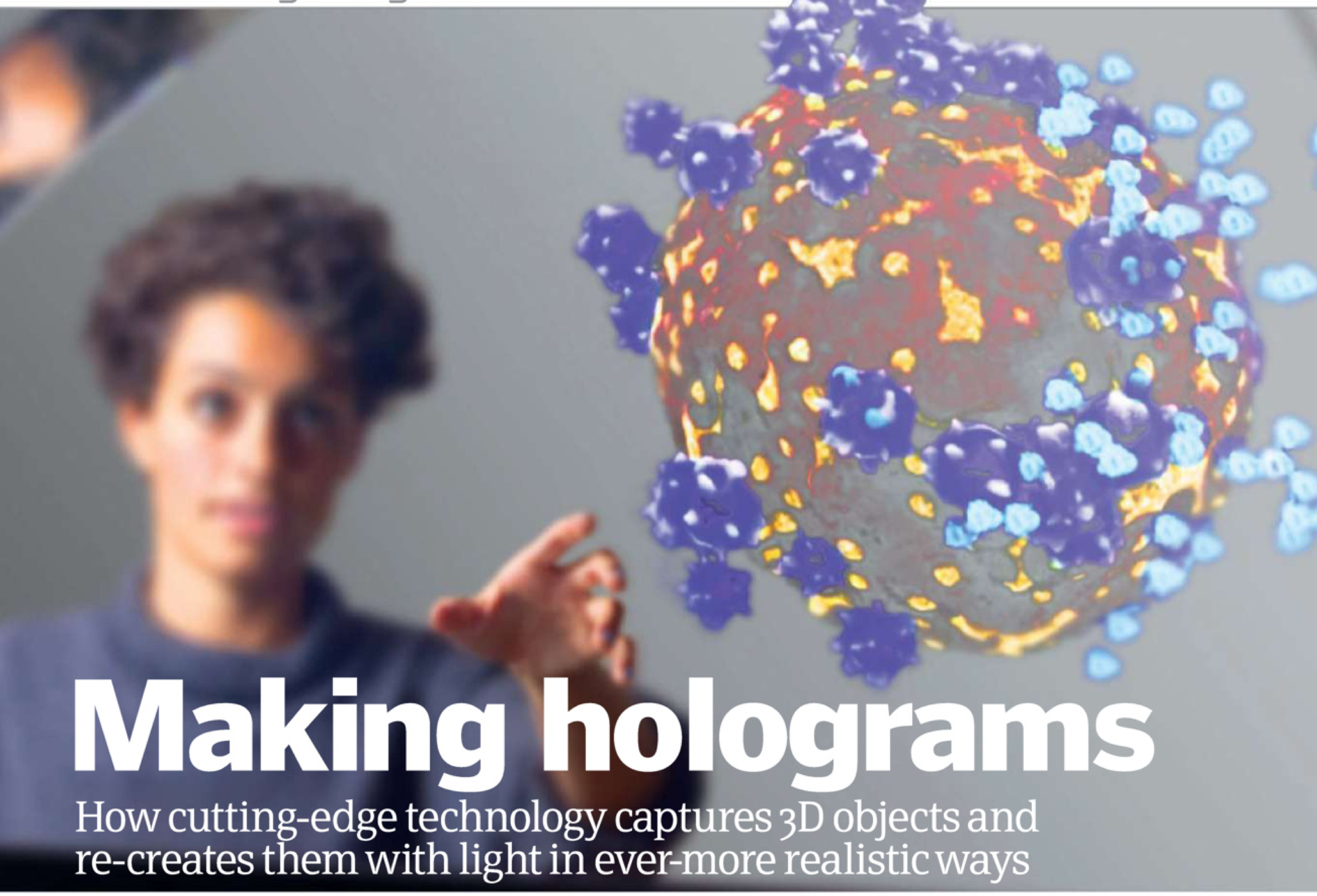
Where would industry be without the invention of an electron gun?
Until recently you'd have had no TV sets, but that wouldn't matter, because you'd have nothing to watch, as radio/TV transmitters use an amplifier with an electron gun. It's not just TV, though; old-fashioned electrical valves were based on electron beams and so we would have missed an essential step in the development of electronics.

Learn more

For more on electron guns, check out the Diamond Light Source website at **www.diamond.ac.uk**

diamond

©Getty; Diamond Light Source



Making holograms

How cutting-edge technology captures 3D objects and re-creates them with light in ever-more realistic ways

The principle of making a hologram is similar to recording an orchestra in surround sound – once the sound has been recorded, the orchestra can stop playing and the sound can be re-created again and again without any instruments.

Instead of recording audio, a hologram stores the interference pattern generated by light scattered by an object. This allows that light scatter to be reproduced later, giving the illusion the object is still there.

Capturing a hologram requires a laser light source – most often a red helium-neon laser. The light is divided by a beam splitter and each new beam travels a separate path to the holographic recording plate. The first beam – the object beam – travels to the object itself, while the second goes to a recording plate as a reference to obtain the interference pattern.

Before they reach their targets, each beam travels through a lens. Unlike the lens of a camera, the lenses of a holographic recorder are not designed to focus light, but instead spread it out. As the object beam strikes the object, light is reflected and refracted, some of it in the direction of the holographic recording plate. As the object beam reaches the plate, it collides with the reference beam, generating an interference pattern. Interference is recorded using fine grains of photosensitive chemicals, similar to those used in photography.

In essence, the exposed holographic plate is more like a CD than a photographic negative. The stored information cannot be deciphered with the naked eye, instead appearing as a series of bumps and wavy lines. In order to actually view a hologram, a light source must be applied to the film.

There are two main types of hologram, with each viewed in a different way. To look at a transmission hologram, a monochromatic light is passed through the film, producing a floating three-dimensional image of a single colour (most often green). Alternatively, reflection holograms, like those found on bank notes, bounce back light and can be multicoloured.

The process of creating a hologram is incredibly light-sensitive, much like traditional photography, so holographic recording is done in a darkroom. Due to the red colour of most holography lasers, traditional red darkroom lights damage the holographic plates, so green or blue-green lights are used instead.

Holography is also much more sensitive to environmental conditions than photography; so much information is packed into such a small space that even minute deviations in the lasers can ruin the hologram. Vibrations in the floor, in the air from body movement or even as people breathe can disrupt the delicate recording process.

Despite the difficulties in creating holograms, the storage capacity they provide is quite

5 TOP FACTS
HOLLYWOOD HOLOS

Iron Man

1 In the live action *Iron Man* films, starring Robert Downey Jr, eccentric entrepreneur Tony Stark uses holographic projection to manipulate three-dimensional prototypes.

Star Wars

2 In the *Star Wars* universe, holography is used as a form of video communication. They are monochrome and visible from all sides, much like real holograms existing today.

Minority Report

3 In Steven Spielberg's 2002 thriller, Tom Cruise controls a holographic heads-up display using motion sensors on his gloved hands to help prevent future crimes.

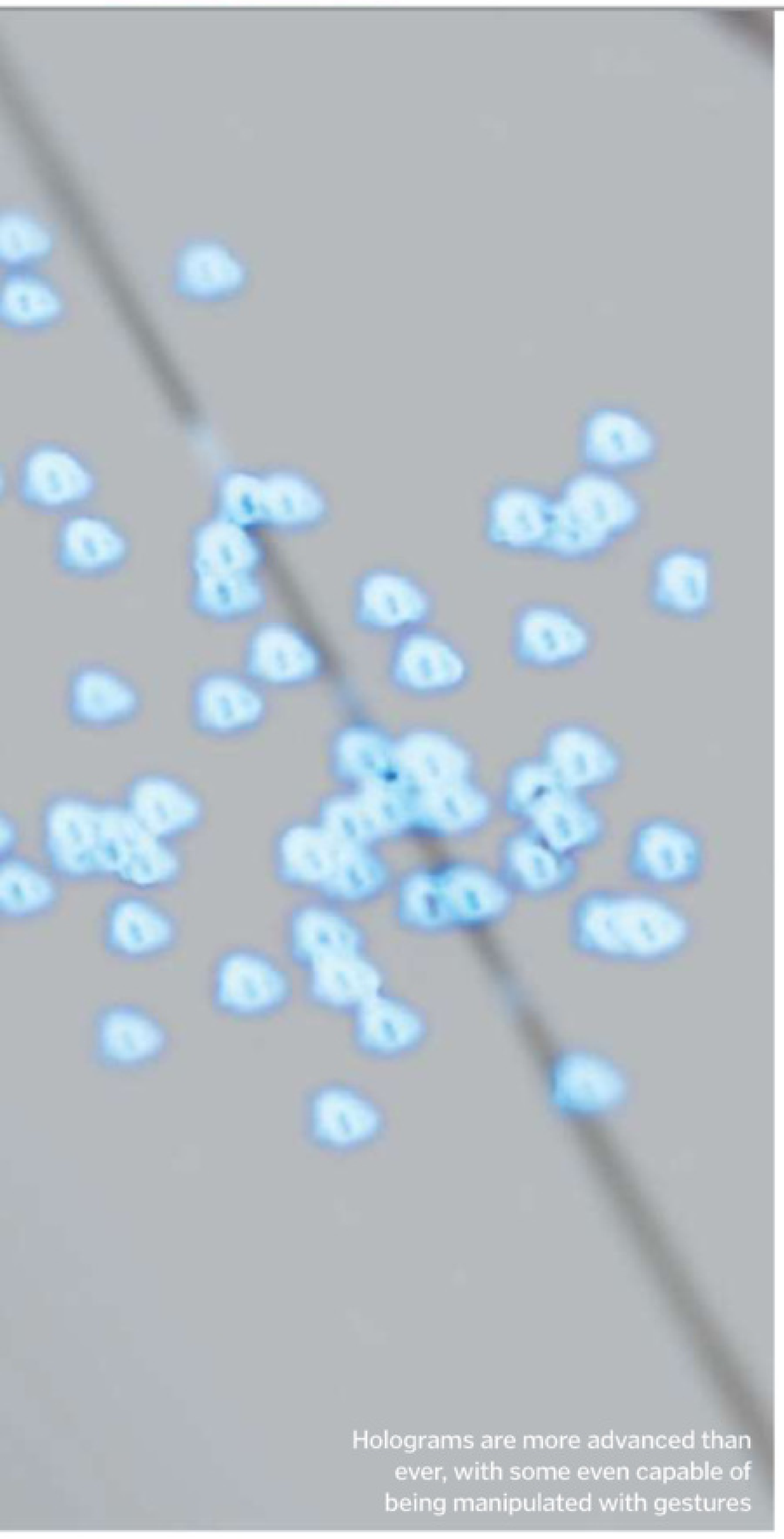
Vanilla Sky

4 A holographic projection of jazz musician John Coltrane appears in the apartment of Tom Cruise during one scene of the 2001 futuristic drama *Vanilla Sky*.

Back To The Future Pt II

5 This 1989 film predicted that by 2015, holographic displays would be used to advertise films like *Jaws 19*. Now in 2014, a similar real-life display advertised *Captain America 2*.

DID YOU KNOW? *Some physicists hypothesise that our universe is actually a hologram, while the 'true' universe is two-dimensional*



Holograms are more advanced than ever, with some even capable of being manipulated with gestures

simply incredible. Holographic images are truly three-dimensional and can be viewed from all angles. The images are also scalable and holograms made with one wavelength can be viewed with another – the size of the resulting hologram scaling with the wavelength of viewing light. In theory, this means that holograms of extremely small structures, down to the molecular scale, could be created using X-rays and then viewed using visible light, although this is yet to be done.

One of the major challenges in holography is producing moving holograms - much like camera film, when conventional holographic recording plates are exposed, the image is fixed. Scottish company Holoxica has developed a holographic screen capable of storing prerecorded holographic images. The screen is illuminated from behind, generating a holographic projection above. The screen can switch between the prerecorded images to

Waking the dead

In 2012, the audience at music festival Coachella were surprised and amazed when the rappers Snoop Dogg and Dr Dre were joined on stage by the musician Tupac Shakur, who died in 1996.

Using a combination of video footage, CGI, body doubles and motion capture technology, it is now possible to digitally resurrect deceased performers, and bring them back to the stage. This illusion was created using the Musion Eyeliner, and we spoke to Liz Berry, director at Hologramica, about how these incredible illusions are produced and projected.

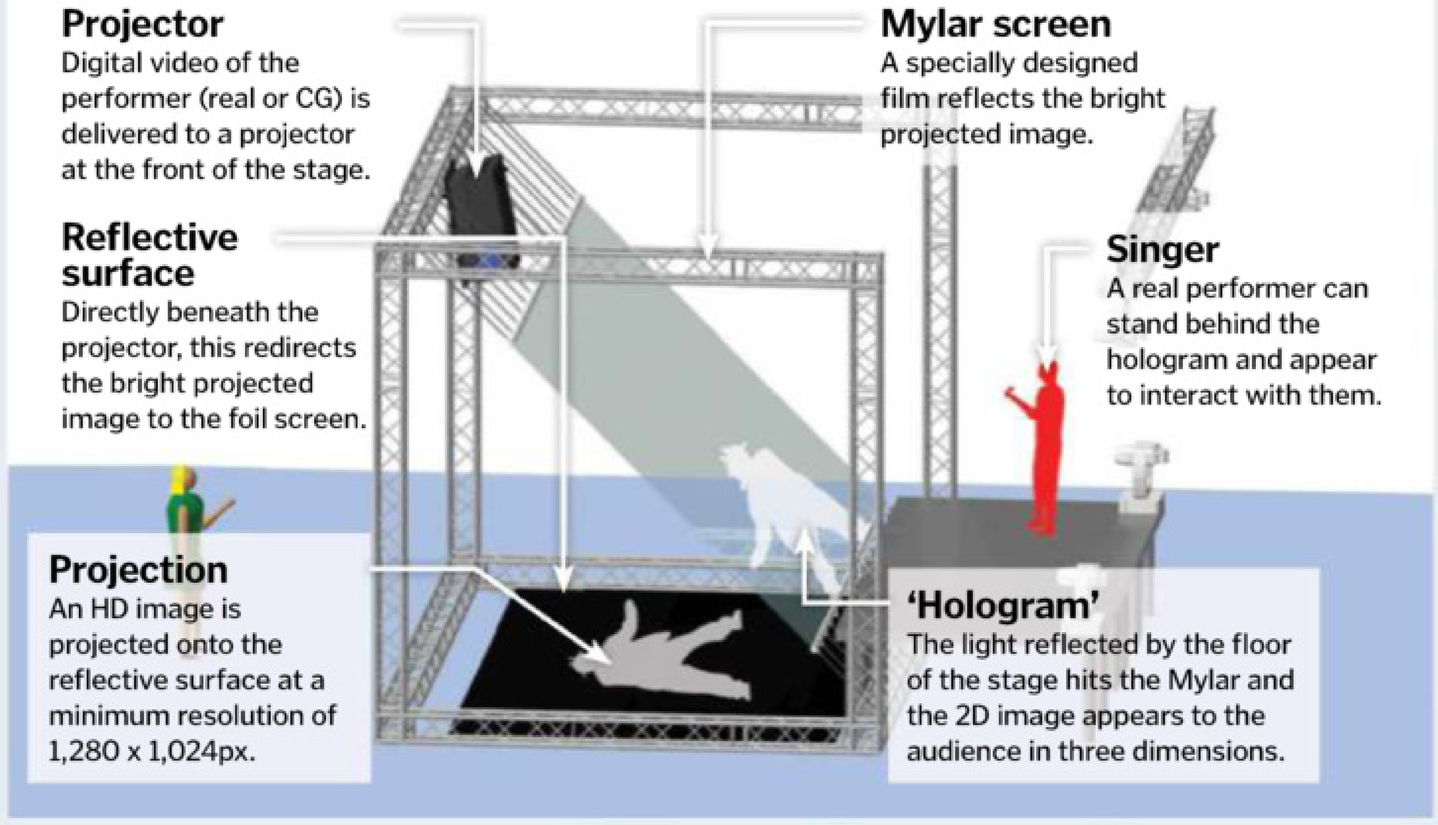
"You need a continuous full body shot of the subject(s) being projected as HD video. This can be achieved by doing a film shoot, or you may be lucky and find existing footage for someone you can't film. Alternatively you can use CGI. Sometimes it's a mix. So, for example, Frank Sinatra was created with both old footage and new film, using CGI to combine the two as a lifelike hologram.

"Every element of the presentation has to feel authentic. The lighting has to be right, and that's the single most important factor. But for me it has to start with the design of the stage itself to give you the most effective and elegant way of deploying physically bulky equipment that has to be placed accurately. Some considerations are purely technical, others are creative and take a good image and enhance it by finding ways to blend the real and the virtual seamlessly."

Thanks to hologram technology, deceased rapper Tupac was able to grace the stage once more

Digital resurrection tech

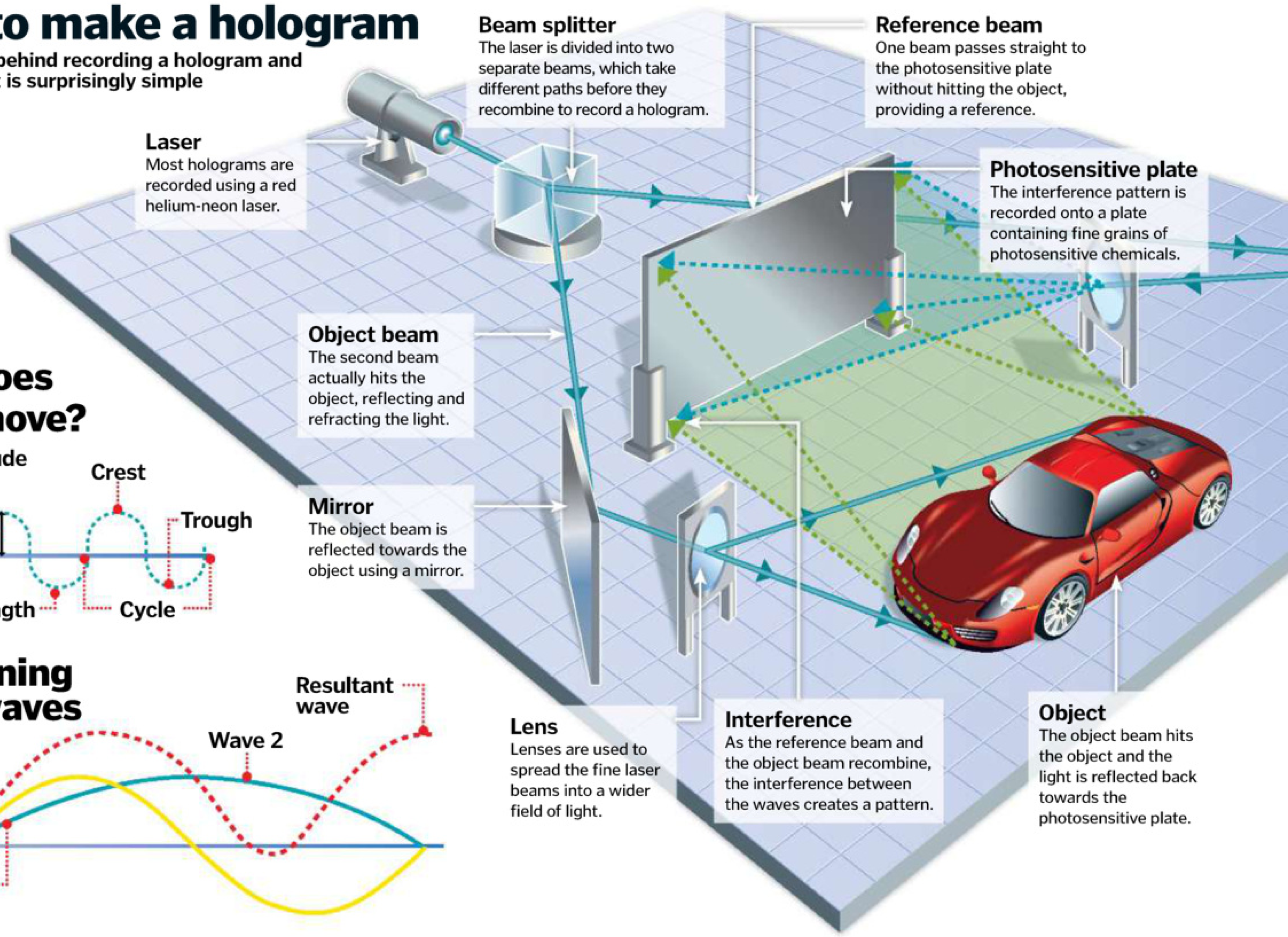
Using a 21st-century version of a Victorian theatre trick, singers can perform to millions from beyond the grave



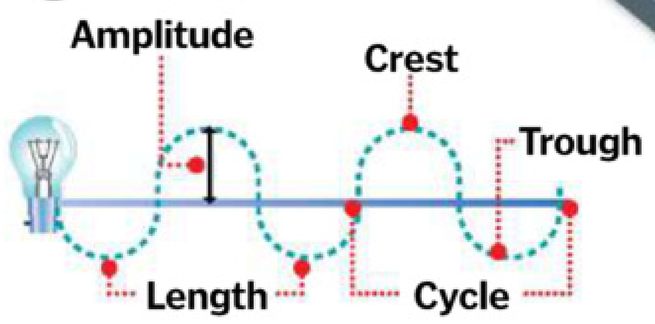
Making holograms

How to make a hologram

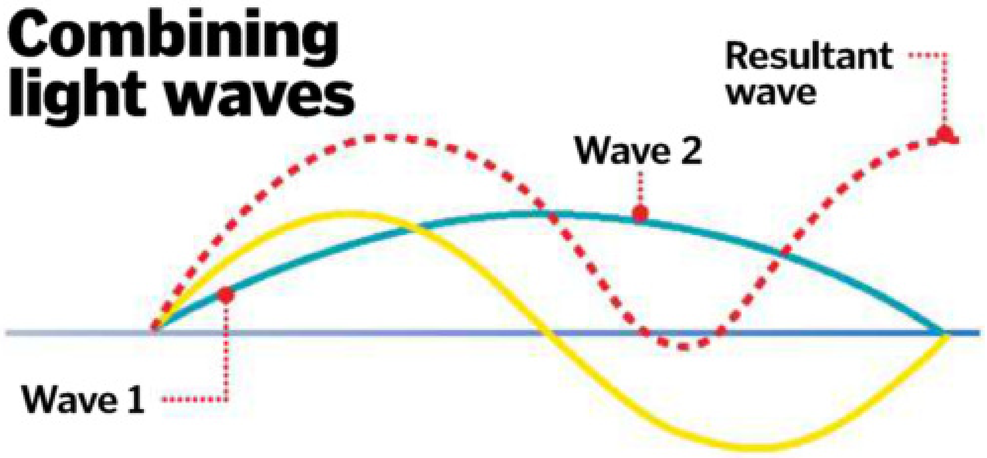
The science behind recording a hologram and re-creating it is surprisingly simple



How does light move?



Combining light waves



change the visible projection. By using collections of simpler interference patterns more complex images can be created, a bit like pixels forming an image on an LCD screen.

True moving holograms might not be here yet, but companies like Musion, AV Concepts and Hologramica are using advanced digital media techniques to create realistic, life-size 3D projections that are the next best thing. Between them, they have given form to the animated band Gorillaz, staged a piano battle between a musician and his holographic double, and even brought musicians back from the dead (see the 'Waking the dead' boxout).

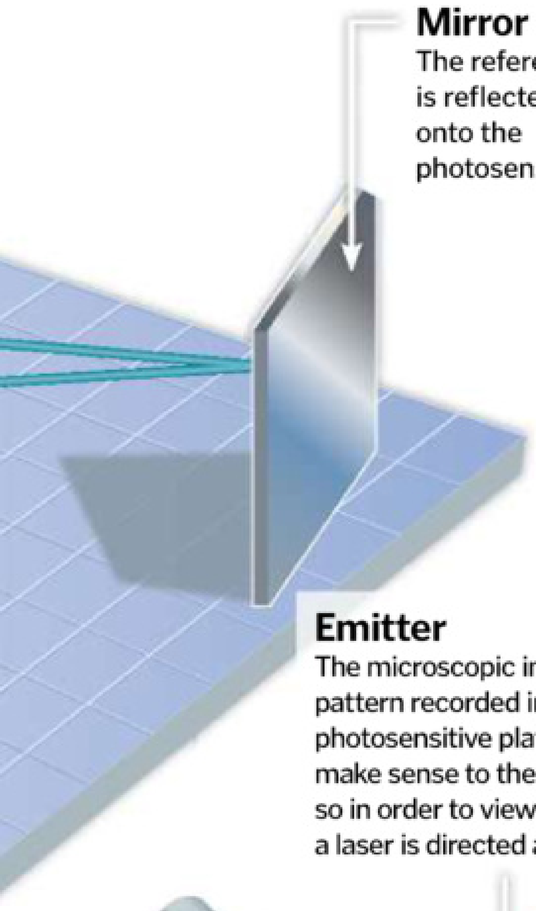
We spoke to Liz Berry, the director of 3D holographic projection company Hologramica, about the secret behind these incredible stage shows – an old illusion known as Pepper's Ghost: "Pepper's Ghost was originally used in Victorian theatres to make supernatural effects. They would place a lit performer out of the audience's view and position a piece of glass between the performer and the audience. The viewers wouldn't know they were viewing the stage through the angled glass because it's transparent, and the lit actor's reflection would appear as a ghostly apparition. The modern take uses bright HD video and the glass is now a specially developed foil. The image is projected onto a concealed screen on the floor so you only see the reflection in the foil, and voila!

"So the holographic illusion is basically HD video in 2D. Although what we create isn't technically a hologram in the truest sense, it's become popularly known as that. I sometimes think we should run a competition to come up with a better name, but I guess we have to stick with hologram for now!"

This tech has been miniaturised by British company Beagle Media, which has developed one of the most advanced hologram players – Holo. Using a Mac Mini and four 140-centimetre (55-inch) Samsung panels, a 2D image is projected to appear in three dimensions. Not only that, but motion sensors allow the object to be manipulated in real-time with gestures.

Illusion techniques are also being used to explore the development of touchable holograms. The mirage toy is a classic illusion; an object is placed on top of a concave mirror, and a second mirror is placed on top. The reflection of the light inside the mirrored chamber focuses the image just above an opening at the top, making it appear as though the object is sitting outside of it.

Researchers at the University of Tokyo are using it as a tool to develop holograms we can interact with. Hand movements are tracked using infrared sensors from Nintendo Wii remotes, while airborne ultrasound signals create tiny pressure waves that mimic the sensation of touch. Microsoft is developing similar technology with Kinect.



The potential for these kinds of technology is vast. Not only can holographic images be used for entertainment, art and education, but the potential applications in medical science, technology design and augmented reality are huge. Doctors in Israel are already using interactive holograms to help perform surgery by re-creating real-time models of organs during operations, while research at the Human Media Lab at Queen's University in Ontario, Canada, is at the early stages of designing a 3D version of Skype (pictured right).

True moving holograms might currently look like LCD screens from the 1980s, but look at where those screens are now. For Holoramica, it's all about achieving the impossible: "[We can] make cars float, turn ballerinas into crystal swans, and do things on stage that you can't do by any other means; people engage emotionally with these images as well as just looking at them. Seeing is believing."

The man behind the hologram

Hungarian-British engineer Dennis Gabor was awarded the Nobel Prize for Physics in 1971 for the invention of the holographic method. He realised that optical imaging only records the amplitude of waves, not the phase, and that if you recorded both, a three-dimensional image could be captured. Despite conceiving his initial ideas in 1947, the laser was not invented until 1960 and it was not until 1964 that the first hologram was made.

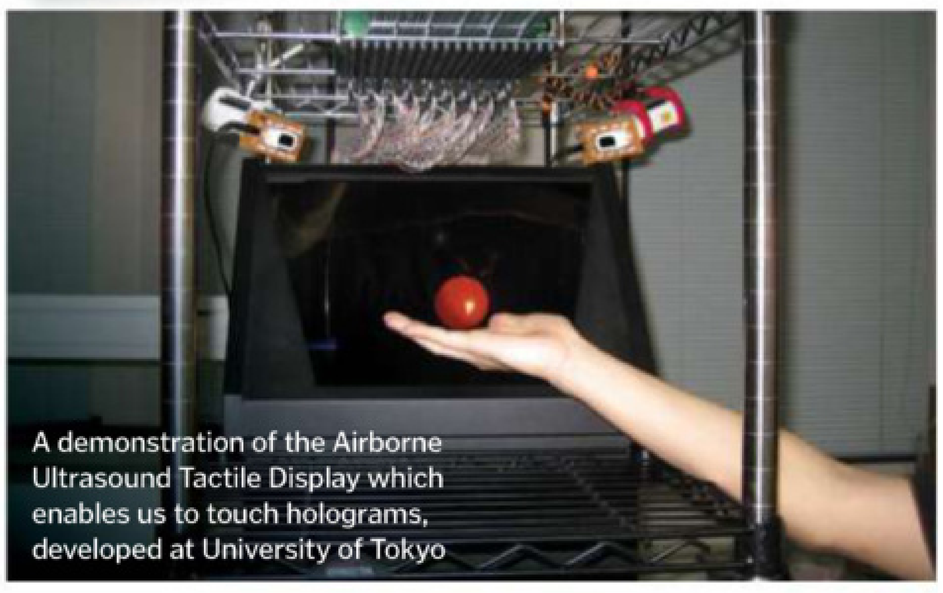
5 reasons why holograms beat CDs hands down

- ✔ Higher storage capacity
- ✔ Faster data transfer
- ✔ Long-term stability
- ✔ Unaffected by magnetic fields
- ✔ Smaller size

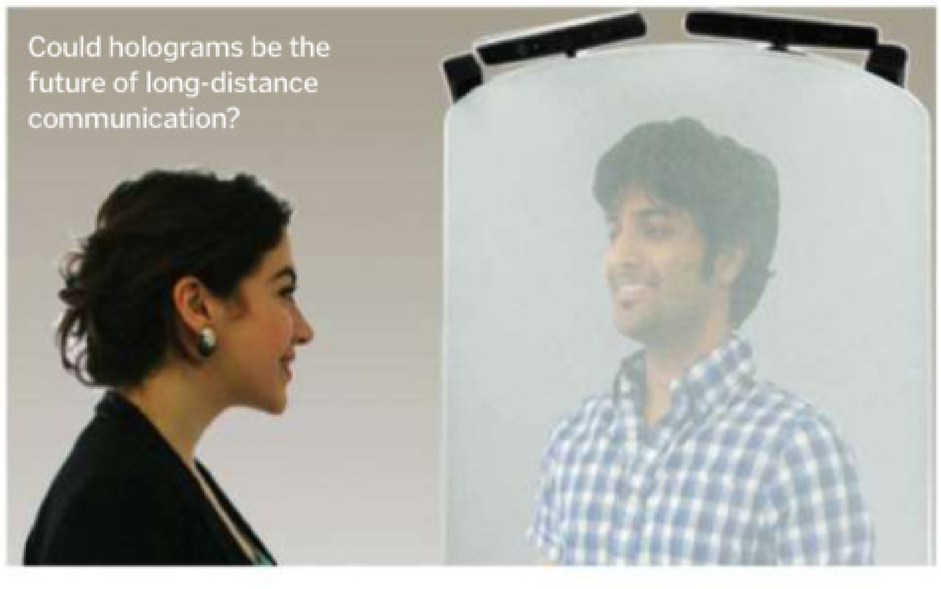
The future of data storage

Holograms aren't just useful for displaying 3D images in art galleries and at music festivals; they could also be the next big thing in data storage.

Conventional storage methods, like CDs and DVDs, can only store information in two dimensions, can only be accessed from one angle, and must be read in series as the disk spins. By representing binary information visually, as clear and black boxes, it is possible to store it in hologram form. A 3D storage hologram could be read, and written to, from all angles, and different areas could be accessed in parallel, allowing compact storage and superfast replay.



A demonstration of the Airborne Ultrasound Tactile Display which enables us to touch holograms, developed at University of Tokyo



Could holograms be the future of long-distance communication?

Everyday holograms

1 Security hologram
Perhaps the most widely recognised and are used to mark items like credit cards, bank notes and passports. The images are hard to replicate and are used to prevent counterfeiting and fraud.

2 Museum archiving
Holographic records of museum artefacts not only enable them to be shared worldwide, but they also allow curators to monitor any deterioration in the condition of their collection. It also serves as evidence in case an item is lost or stolen.

3 Medical imaging
Instead of viewing a simulated 3D image on a screen, doctors are finding it increasingly useful to convert digital images taken by medical scanners, including MRI and ultrasound, into holograms.

4 Barcode scanners
Holographic scanners use laser beams to explore barcodes. Each beam follows a different path, generating a three-dimensional image of the barcode, allowing it to be read from any direction, even if the scanner is facing the side of the packet.

5 Heads-up display
Holographic HUDs effectively superimpose a navigational display onto a pilot's view out of the cockpit. Advances in hologram technology will soon enable HUDs to be incorporated into the glass of car mirrors too.

© Alamy; AV Concepts; Beagle Media; Corbis; Shinoda Lab, University of Tokyo; Human Media Lab, Queen's University; Ian Moores Graphics

How panic rooms work

What goes into the ultimate home defence unit?

Panic rooms hit the spotlight in 2002 when Jodie Foster and Kristen Stewart starred in a film where they were trapped in one, but what are these modern-day boltholes and how are they constructed?

A panic room is a safe place for occupants of a property to go whenever they feel threatened. The danger could be in the form of an intruder or a natural threat like an earthquake or hurricane. These rooms are typically windowless for maximum security and the only weak point of these rooms might be the door, but to combat this, panic room doors are constructed from super-thick steel, have reinforced frames and are fitted with high-level security locks. Fingerprint scanners or keycode entry pads provide an extra barrier, and sometimes the door is so well concealed that a trespasser may not even know the room exists.

The room must provide all the essentials for staying alive during a potential long-term situation, so basic plumbing, air filtration and a good stock of medical kit, food and water are all standard. The most expensive panic rooms might also feature monitors hooked up to a CCTV system to keep an eye on intruders' movements as well as a means of communication to contact the outside world.

Thankfully, most panic rooms aren't as tension-filled as 2002's *Panic Room*

A game of hide and seek

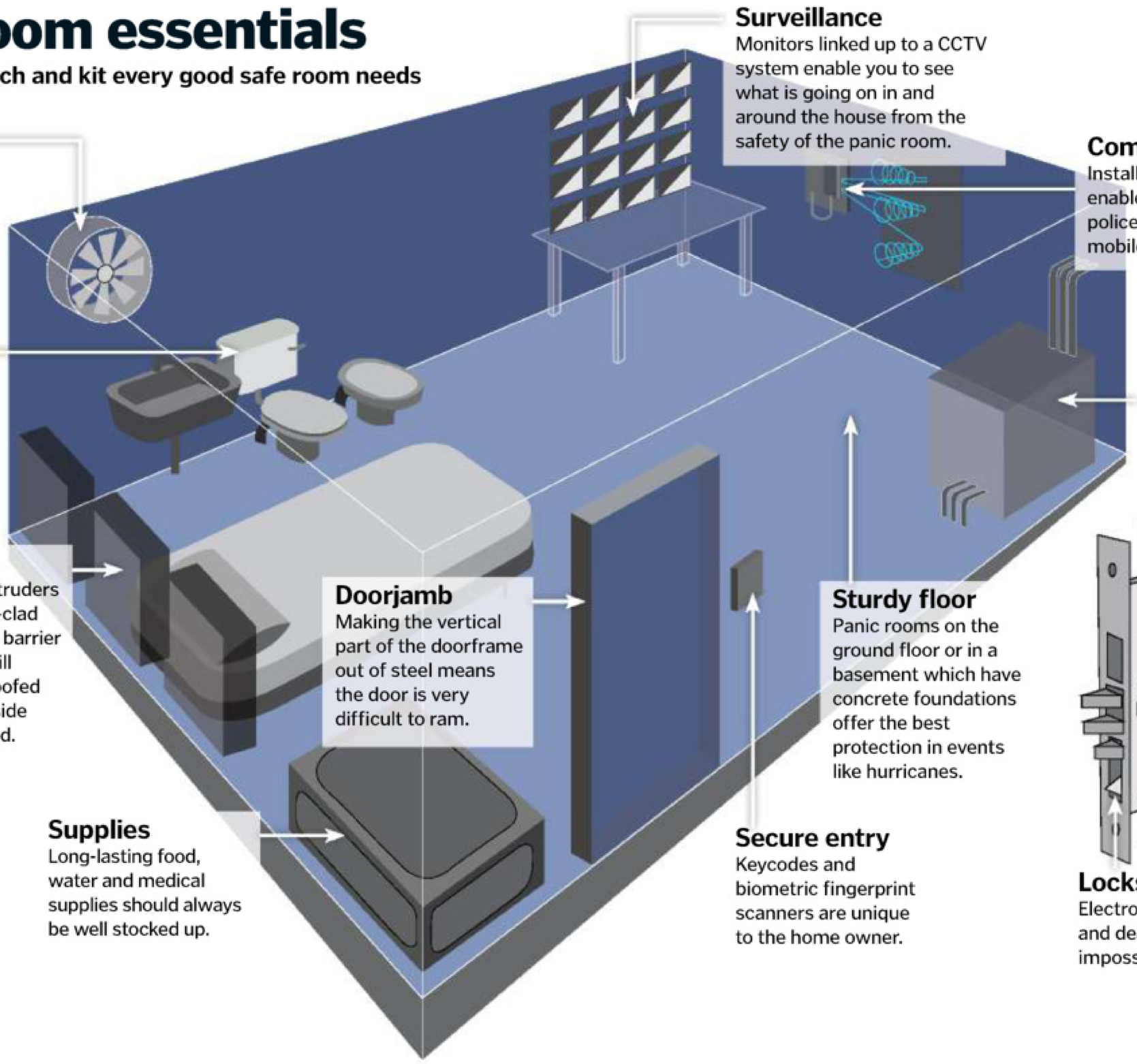
People who are designing custom-built panic rooms to evade intruders are constantly coming up with new and more ingenious ways of keeping these hideaways, well, hidden.

While secret rooms behind bookcases may seem more in line with Enid Blyton fiction than real life, the fact is that a hidden entrance to a panic room could prevent assailants even knowing you're in the building, making it the ultimate defence.

There are examples of panic room doors hidden behind sliding walls, underneath floorboards or through the back of a closet. To ensure a panic room is as well hidden as possible, companies are offering tailor-made services, creating precisely constructed moving walls, which can barely be seen without prior knowledge. Although these are very costly, the peace of mind that comes with increased safety often takes precedence.

Panic room essentials

Explore the key tech and kit every good safe room needs



Air filtration
If you're going to be in an enclosed environment for a while, a system for circulating fresh air is a must.

Plumbing
Nature will inevitably call if stuck in the room for some time, so a toilet is a must and a sink provides essential water.

Kevlar walls
If there's a risk that intruders may be armed, Kevlar-clad walls provide an extra barrier of protection. Walls will generally be soundproofed too so you can talk inside without being detected.

Supplies
Long-lasting food, water and medical supplies should always be well stocked up.

Doorjamb
Making the vertical part of the doorframe out of steel means the door is very difficult to ram.

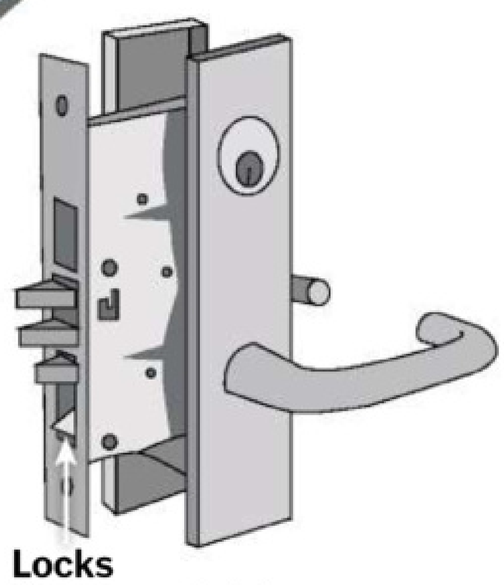
Surveillance
Monitors linked up to a CCTV system enable you to see what is going on in and around the house from the safety of the panic room.

Communication
Installing a landline or radio enables you to contact the police or family in case your mobile has no signal.

Generator
For long stays an internal power source is vital, so a small generator can offer both light and heat.

Sturdy floor
Panic rooms on the ground floor or in a basement which have concrete foundations offer the best protection in events like hurricanes.

Secure entry
Keycodes and biometric fingerprint scanners are unique to the home owner.



Locks
Electromagnetic locks and deadbolts are next to impossible to break through.

© Alamy

RECORD BREAKERS
ROWING FEAT

6 HUNDRED

MOST ROWERS IN 24 HOURS

On 8 March 2013, 600 people rowed 500m (1,640ft) each in 24 hours at Mercyhurst University in Pennsylvania, USA.

DID YOU KNOW? *Sir Steve Redgrave produced up to 500W during his Olympics races, enough to power a PC for six hours*

Gore-Tex

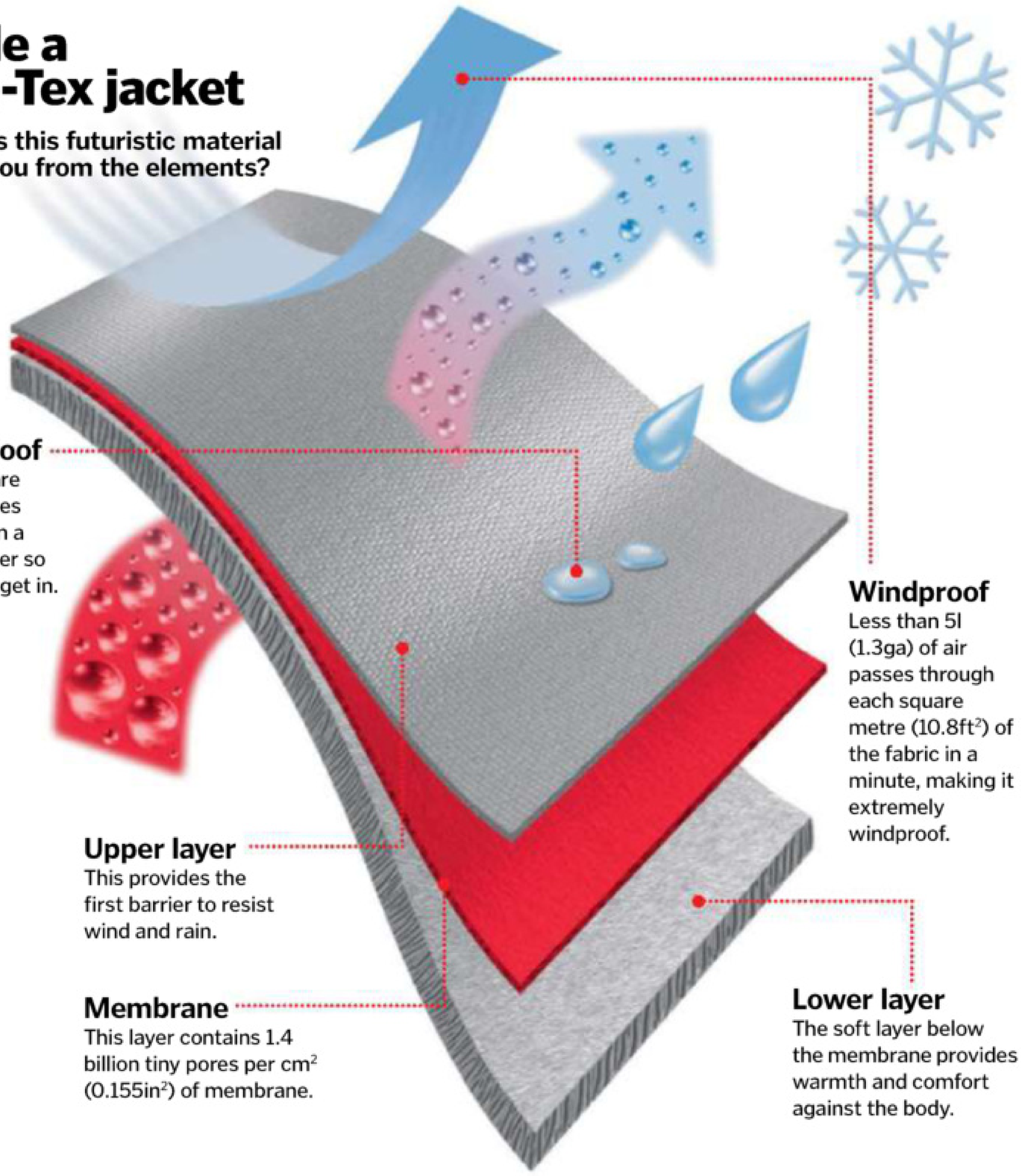
The science behind this waterproof and windproof material

Gore-Tex clothing is a favourite among hikers because it keeps Mother Nature at bay. Unlike nylon – which is waterproof but traps sweat – Gore-Tex is a 'breathable' fabric. It has all to do with a thin membrane embedded in the garment where there are 1.4 billion pores per square centimetre (0.155 square inches). As each pore is larger than a water vapour molecule, sweat is able to escape through the fabric. These tiny pores also massively reduce the amount of wind that can get in.

This doesn't stop it being waterproof, however. Even though each pore is bigger than a water vapour molecule, it is smaller than a liquid water molecule, so rain is unable to get through to your body.

Inside a Gore-Tex jacket

How does this futuristic material protect you from the elements?



Waterproof
The pores are 20,000 times smaller than a drop of water so no rain can get in.

Windproof
Less than 5l (1.3ga) of air passes through each square metre (10.8ft²) of the fabric in a minute, making it extremely windproof.

Upper layer
This provides the first barrier to resist wind and rain.

Membrane
This layer contains 1.4 billion tiny pores per cm² (0.155in²) of membrane.

Lower layer
The soft layer below the membrane provides warmth and comfort against the body.

How rowing machines work

The first step to becoming the new Sir Steve Redgrave

Rowing machines are a staple of the gym, but how do they work and what does that lever on the side actually do? The entire system of indoor rowing works on the principle of resistance. When you pull the chain back it spins a flywheel inside the housing. As you return to the starting position the chain winds back round, ready for another tug on the flywheel.

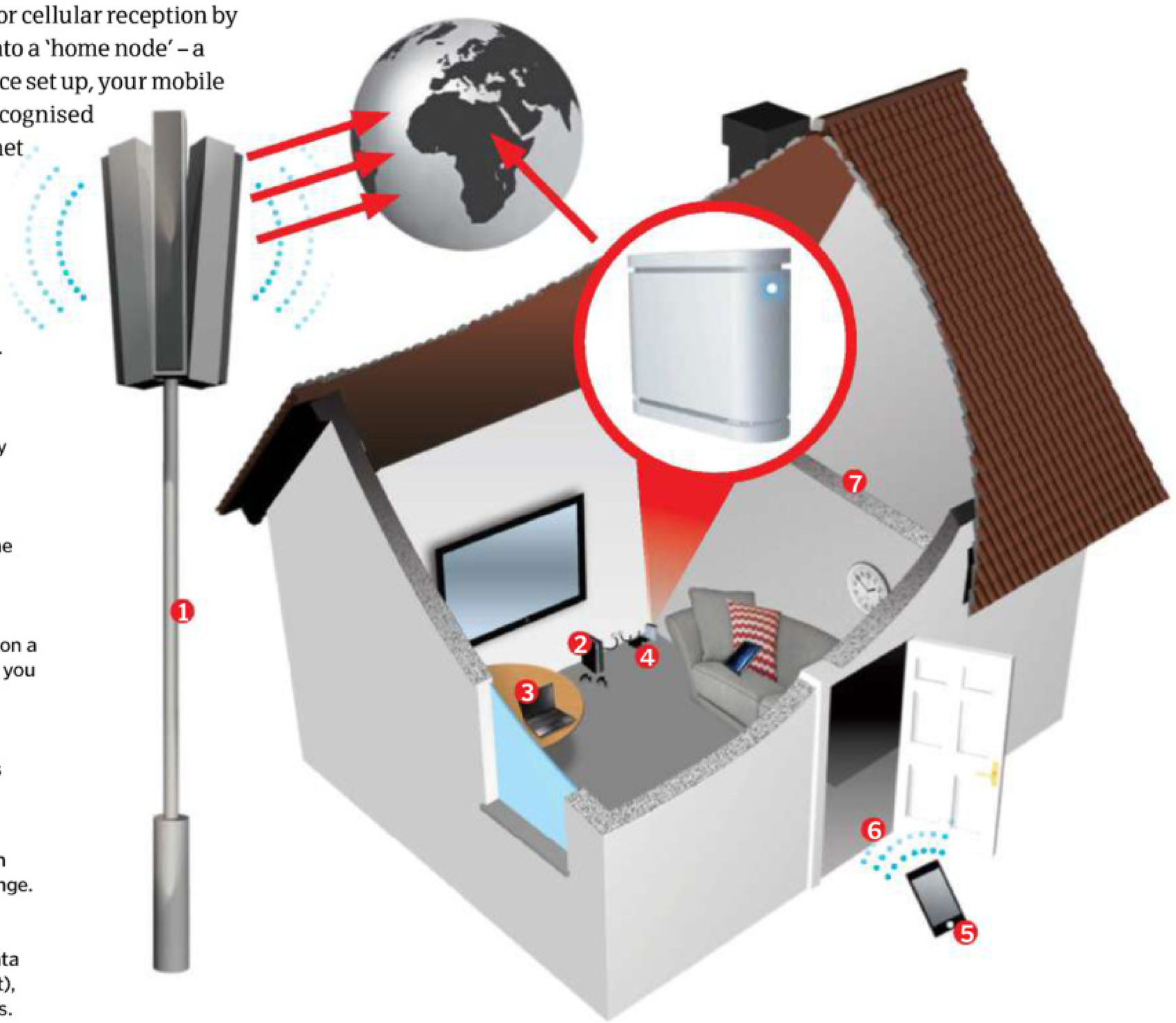
The lever on the side is called the damper and this affects how much air is allowed into the system. When the setting is higher, more air is able to get in, making the flywheel harder to rotate as it's battling against more air resistance. Even when you're on the return stroke, the air is still working against you, slowing the flywheel down so it takes more effort to pull it back again.

© Thinkstock; Mountain Equipment GTX; Gore

Home nodes explained

Find out why femtocells are perfect if you live in a signal black spot

Femtocells can be the solution to poor cellular reception by turning your broadband landline into a 'home node' – a mini mobile phone base station. Once set up, your mobile phone and other gadgets are automatically recognised and any voice calls use VoIP (Voice over Internet Protocol) data packets to connect a call. Unlike Wi-Fi, femtocells don't drain your devices' battery life either.



❶ Cell tower
Rather than relying on overcrowded cell towers in the area, the femtocell interacts with the internet directly.

❷ No interference
An operator-licensed spectrum is used which means there should be no interference from other technology around the home, like video consoles.

❸ Home network
The femtocell automatically syncs your device with the wider home network for easy media sharing.

❹ Modem
The femtocell is plugged into a spare Ethernet socket on a modem. Input your phone number via a webpage and you can start using all the usual mobile phone services.

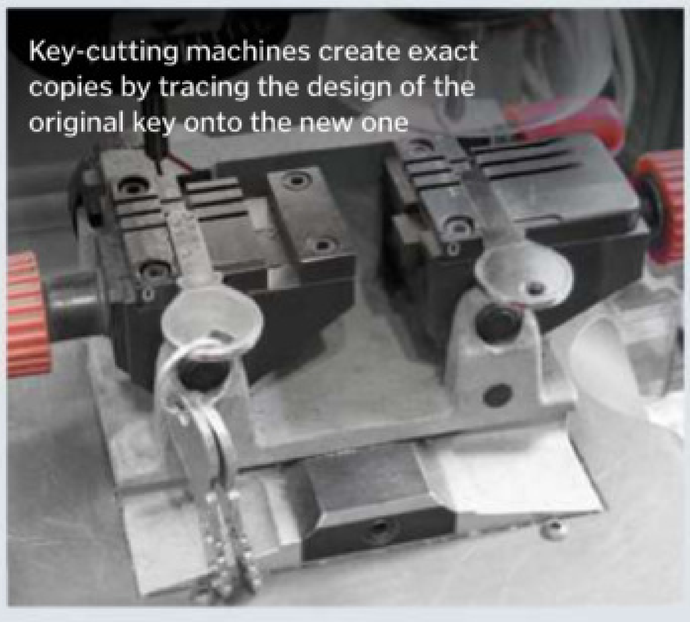
❺ Improved calls
As the femtocell is taking over voice calls, many users experience improved levels of call clarity.

❻ Instant recognition
You can connect many devices to the femtocell, which are automatically recognised when they come into range.

❼ Boosted signal
The femtocell increases the speed and reliability of data transmission, extending the range to about 30m (98ft), improving signal in homes with thick walls/basements.

Duplicating keys

Discover how the unique notches and grooves are added to fit bespoke locks



Key-cutting machines create exact copies by tracing the design of the original key onto the new one

Simple locks have keys based on a series of larger teeth, so many locks can tolerate some inaccuracy, and manual key-cutting machine is still used in duplication. The original is clamped on top of the new key, forming a template. The operator then traces the outline with a cutting blade, producing a duplicate pattern in the new key.

A skilled operator can make nearly identical keys, but it's very time-consuming, and high-security locks require greater precision. Automated key-cutting machines are more accurate. These use the same principle as the original is used as a template, but the keys are clamped separately. A stylus traces the outline of the original and the machine transfers it to the copy using a cutting blade. For higher-security keys, a laser-cutting device is used, allowing for extremely high precision. This technique introduces tiny pits into the surface, increasing the lock's complexity.

Some keys are not copied at all. So-called 'code keys' use a predefined map stored on a memory device. In order to replicate these, you just need the code, containing instructions for the locations and dimensions of the grooves.

© Peters & Zabransky; Thinkstock

How are skyscraper windows cleaned?

Discover how the tallest buildings on the planet keep up appearances

There are three main factors involved when it comes to cleaning skyscraper windows: cleaning equipment, cleaning mechanism technology and environmental considerations.

Due to the epic heights and natural factors like wind involved in the operation, every cleaner is equipped with a harness, descent and safety rope, rope protector, rope-grabbing tool, descent mechanism, lanyard and suction cups. Together these tools enable the worker to negotiate a building's vertical façade at speed, while attached to a roof-mounted anchor. This anchor allows cleaners to descend in 'drops' – the measurement of one vertical cleaning operation from roof to the below floor or platform – without fear of falling.

When group work is necessary, a cleaning mechanism will be employed (see boxout on the right for more information). These mechanical gantries enable teams of cleaners to work in unison and are powered by roof-mounted hydraulic and pneumatic support systems. The ascending and descending of the gantries is dictated by a control panel, but as a backup additional control systems are typically placed on the roof of the building.

Lastly, when cleaning skyscraper windows, workers must constantly be vigilant of potentially deadly environmental factors – the chief one being wind. At the high altitude of skyscrapers, wind flow is not just fierce but highly turbulent, with the building acting as a disrupter to the general environmental flow. These gusts can blow cleaners off course, cause tools to be dropped (risking anyone passing below) and render gantries unusable. Luckily, many modern skyscrapers – such as the world's tallest, the Burj Khalifa in Dubai – are now being designed to smoothly redirect winds around their structures and prevent the buildup of vortices and turbulence.

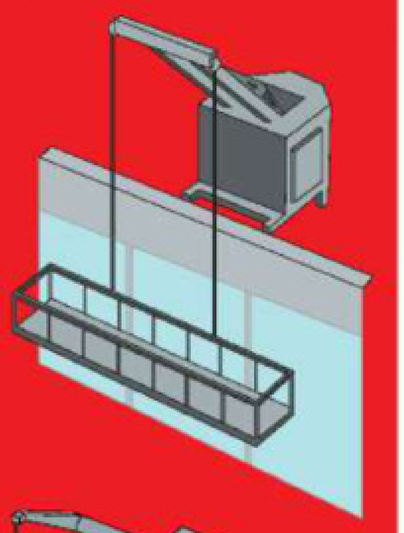
A head for heights is a must for any skyscraper window cleaner!

High-altitude window cleaning

Here are four of the most common skyscraper cleaning mechanisms

Boom

One of the most popular cleaning systems historically, the boom lets a building's façade be accessed easily by a large team. The boom system is permanent and can be operated on-gantry or off.

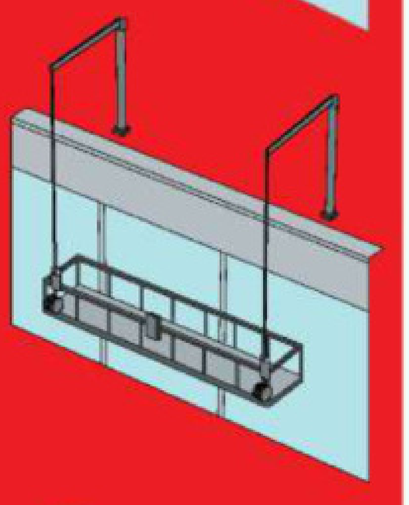


Carriage

These rail-mounted carriages enable gantries to cover larger areas of a building's façade due to their ability to move left and right. As with booms, they are permanent structures and cannot be moved around the building.

Portable davit

The cheapest and simplest solution for cleaning skyscraper windows, portable davits move between fixed bases on a roof, enabling access to different sides of the edifice with just one davit-based system.



Bosun's chair

A more modern development in skyscraper window cleaning technology, the bosun's chair gives a single cleaner access to a tall building's windows from a safe seated position. They are ideal for tight areas and use over long periods.

© Dreamstime

Terrariums explained

Discover how these fish tank-like devices are used to grow tropical plants

Terrariums are a special type of enclosure with a glass case that specialise in re-creating a foreign habitat very different to the room they are located in. Typically they are used to grow plants that can only exist in tropical climates such as croton or selaginella, with a series of lighting, water and circulation systems artificially imitating their native habitat.

Animals can be kept in terrariums too, with turtles being one of the most common inhabitants. However, their prime modus operandi is for botanical or decorative purposes, akin to a fish tank in modern homes and offices. It's worth noting, as can be seen in the 'Get to know your habitats' boxout, terrariums differ from other similar enclosures like insectariums and formicariums.

Indeed, a terrarium's focus on plants and flowers makes it in many ways more akin to a botanical garden's tropical glasshouse than an aquarium, with facilities like the Eden Project in the UK and the Biosphere 2 in Arizona sharing much of its technology, albeit on a far larger and more complex scale. For a closer look at the key components that make up a modern domestic terrarium, check out the main image.

Anatomy of a terrarium

What technology enables us to re-create tropical forests within a small glass sphere?

Misting module
To ensure that the artificial water cycle of the terrarium is well distributed, a misting module in installed.

Lighting
A series of LED lights is mounted within the lid to replicate necessary levels of illumination and heat for the plants to grow effectively.

Tank
Terrarium tanks are similar in construction to aquariums, consisting of a base, glass tank and lid. Sizes vary, though most are no more than 100cm (39.3in) tall.

Planting tray
The compost for the terrarium's plants is placed on top of a special capilliary mat that draws water from the system's reserves while preventing saturation.

Fans
A fan network attached to an internal carbon filter ensures a supply of fresh air throughout the bowl.

Base
The terrarium's power supply, fans and water reservoir are located within the base. Support struts extend from the base to maintain stability on flat surfaces.

Get to know your habitats...

Aquarium
An aquarium is a simulation of a water habitat, like a river or lake. It can be fresh or salt water and contains marine creatures.

Insectarium
An insectarium is a special type of simulated dry habitat that caters solely to insects and arachnids such as the tarantula.

Vivarium
Similar to a terrarium, albeit designed more for animals, vivariums are typically home to a wide variety of flora and reptiles.

Paludarium
An artificial habitat that re-creates swamp or rainforest habitats. It features aspects of both aquariums and terrariums.

Formicarium
Similar to the insectarium, the formicarium is an artificial habitat that re-creates conditions for ant colonies.

Riparium
A riparium is a very particular type of paludarium – one in which the contained water sources have a circulating current.

© Reef One; Steve Jurvetson

5 TOP FACTS
POOL OF FABRICS

Cotton
1 The most basic of the costumes, cotton swimsuits aren't the strongest or the most hydrodynamic but they are usually the most comfortable to wear.

Nylon
2 Nylon is the most commonly used material for swimwear due to its light weight and strength, but struggles in the Sun's rays where it can fade, and it also frays over time.

Polyester
3 Polyester is strong and comfortable but its range of merits pales in comparison to nylon so polyester is primarily used in other types of clothing rather than swimsuits.

Spandex
4 Most commonly known as Lycra, spandex boasts excellent elasticity. It is often used with other fabrics as it doesn't hold up well to chlorine and can be itchy.

Polyurethane
5 The pantomime villain of swimsuit materials as it has been banned in competitions. The material enclosed tiny pockets of gas that made swimmers more buoyant.

DID YOU KNOW? *The world's most expensive bikini is made entirely of diamonds and is worth an estimated £18mn ($30mn)!*

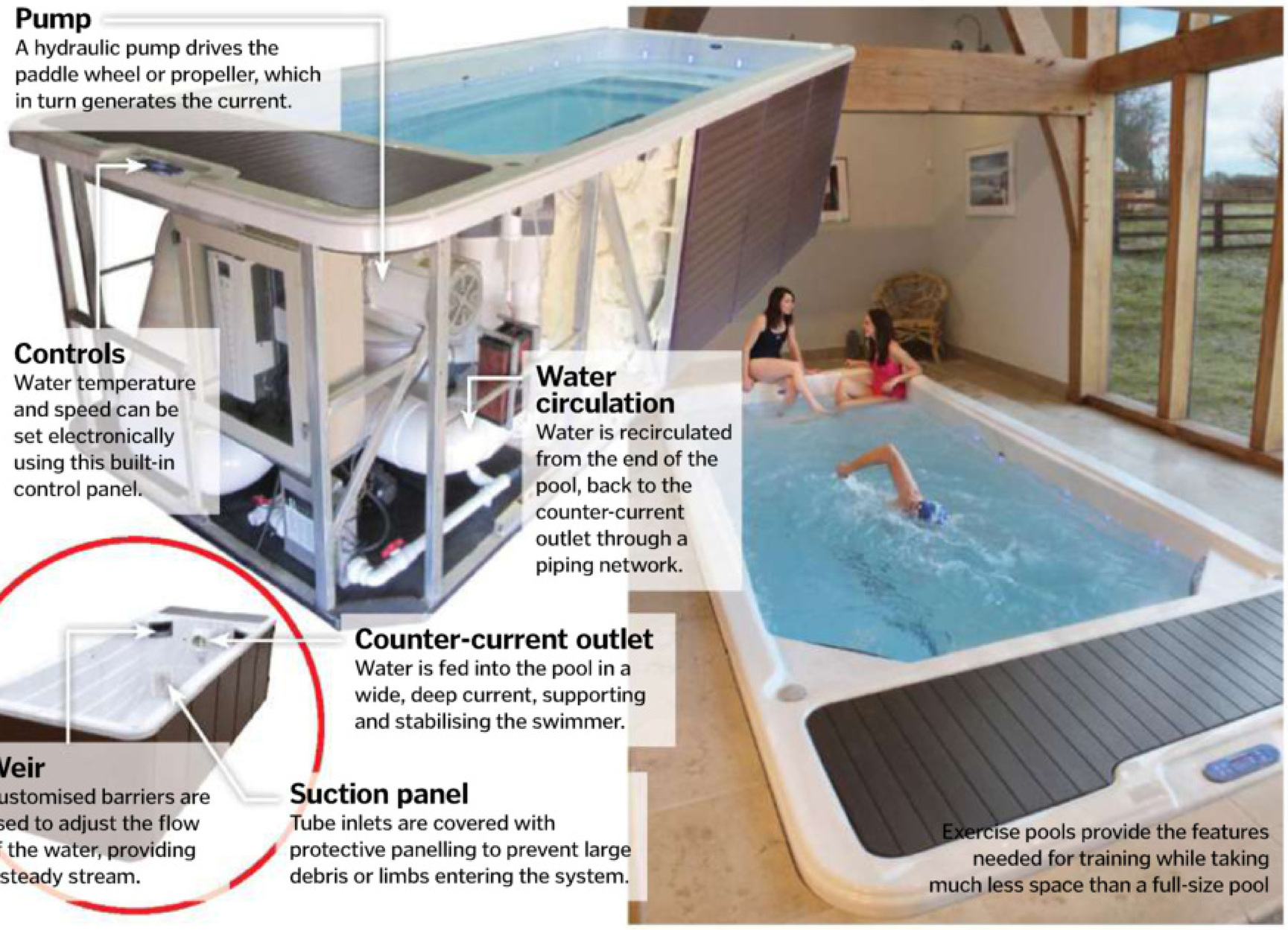
How exercise pools work

Inside the domestic swimming machines that let us swim for miles on the spot

Exercise pools are the equivalent of a treadmill for swimmers. Usually only measuring twice the length of an average person, these compact training pools allow swimmers to practise, using a counter-current system to provide a continuous flow of water to swim against.

Water is pumped using a propeller or paddle wheel and enters the pool at the front end. The speed of the current is adjustable and the water is pumped at low pressure, entering the pool in a wide stream. This minimises the bubbles and turbulence associated with the kind of jet used in Jacuzzis.

Tubes running from the back end of the pool carry water around the outside and return it to the pump, allowing the swimmer to train without the need for a full-size swimming pool or a wave machine.



Exercise pools provide the features needed for training while taking much less space than a full-size pool

Why racing swimsuits make us faster

The streamlined fabrics and designs making waves in competitive swimming

Although they may look simple, swimsuits have been engineered to help swimmers glide through the water.

Most important is the hydrodynamic shape. New materials are designed to reduce drag and compress the body into its most streamlined form, helping to reduce lactic acid buildup in the muscles. The fabrics can be made from nylon or spandex and are designed to be lightweight and have a high compression-to-weight ratio. Bonded seams, for instance, reduce drag by six percent compared to sewn seams.

Suits made of hydrophobic (water-resistant) microfilament textiles can reduce drag by eight per cent. They work by effectively pushing the water away from a swimmer's body.

All these measures help swimmers get ever quicker. So quick in fact, that in 2010, polyurethane suits were banned from competitive swimming as they gave an unfair advantage after records tumbled at the 2009 World Swimming Championships.

Comfort for the swimmers is also a priority of course. Special widened straps help avoid soreness while wide-vision goggles aid sight and reduce drag. Even harmful chemicals are combated with new materials resisting chlorine up to ten times longer than older suits.

Swimsuits have become a hi-tech aid to competitive swimmers in recent years

© Speedo; Corbis

Growing plants without soil

Hydroponic systems already grow tomatoes and lettuce, and might one day produce new superfuels

Hydroponics is a system of growing crops in nutrient-enriched liquid baths rather than soil. Normally, roots anchor the plant in the ground and absorb all the water, minerals and nutrients from the soil the plant needs in order to grow. They cannot break down the soil particles but rely on the dissolved solution between them.

Hydroponics does away with soil and grows plants with their roots suspended in an aerated nutrient solution in greenhouses. The roots can also be supported in an inert medium, like gravel or sand, and flooded with a fertiliser solution. Tomatoes, cucumbers and peppers grown hydroponically in greenhouses in American deserts produce five to ten times as much crop weight per year as those grown in irrigated, open fields. Worldwide, hydroponic greenhouses now cover an area equivalent to 17,500 football fields and produce crops worth £3.5-4.7 billion ($6-8 billion) a year.

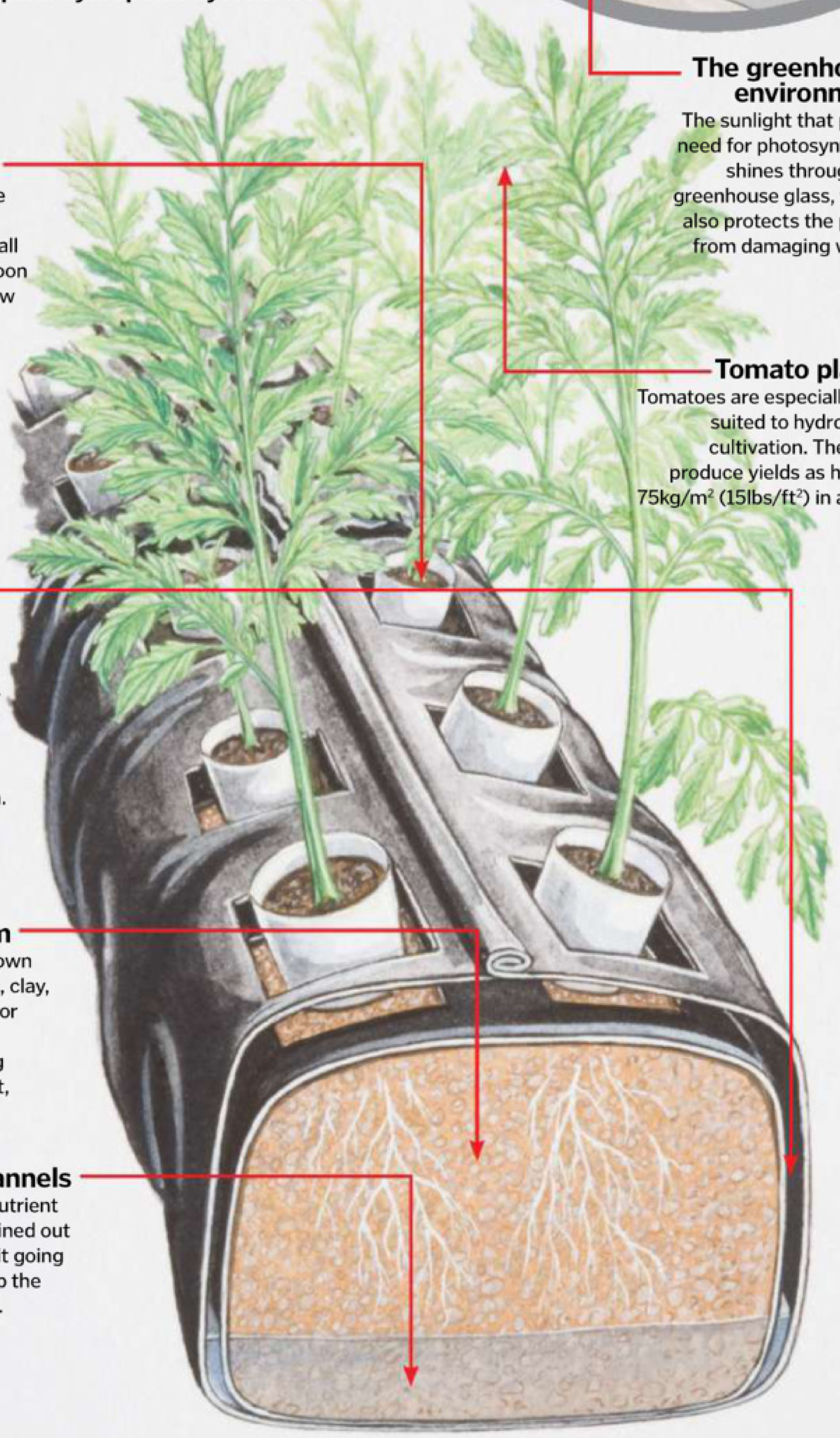
A new use is being developed for hydroponics. Algae (simpler plants) are grown in tanks in the sunshine, absorbing CO_2 from the atmosphere. They develop 20 times as fast as traditional crops, so a portion can be harvested daily. This is fermented to produce ethanol and the mush left behind is buried. This process locks up carbon dioxide, helping to reduce greenhouse gases that cause climate change.

Growth spurt

- THE IDEAL CONDITIONS FOR GROWTH
- RAINWATER IS AN IDEAL SOURCE
- 25°C (77°F): OPTIMUM TEMPERATURE
- PLENTY OF OXYGEN IS NEEDED
- FRESH NUTRIENTS EVERY WEEK
- PH LEVELS SHOULD BE BETWEEN 5 AND 6

The greenhouse effect

How does a typical hydroponic system work?



The greenhouse environment
The sunlight that plants need for photosynthesis shines through the greenhouse glass, which also protects the plants from damaging winds.

Starter pots
In this system, the seedlings are germinated in small pots of soil, but soon their roots outgrow these pots.

Tomato plants
Tomatoes are especially well suited to hydroponic cultivation. They can produce yields as high as 75kg/m² (15lbs/ft²) in a year.

Nutrient bath
A balanced solution of nutrients in water is poured into the inert medium to nourish the tomatoes' growth.

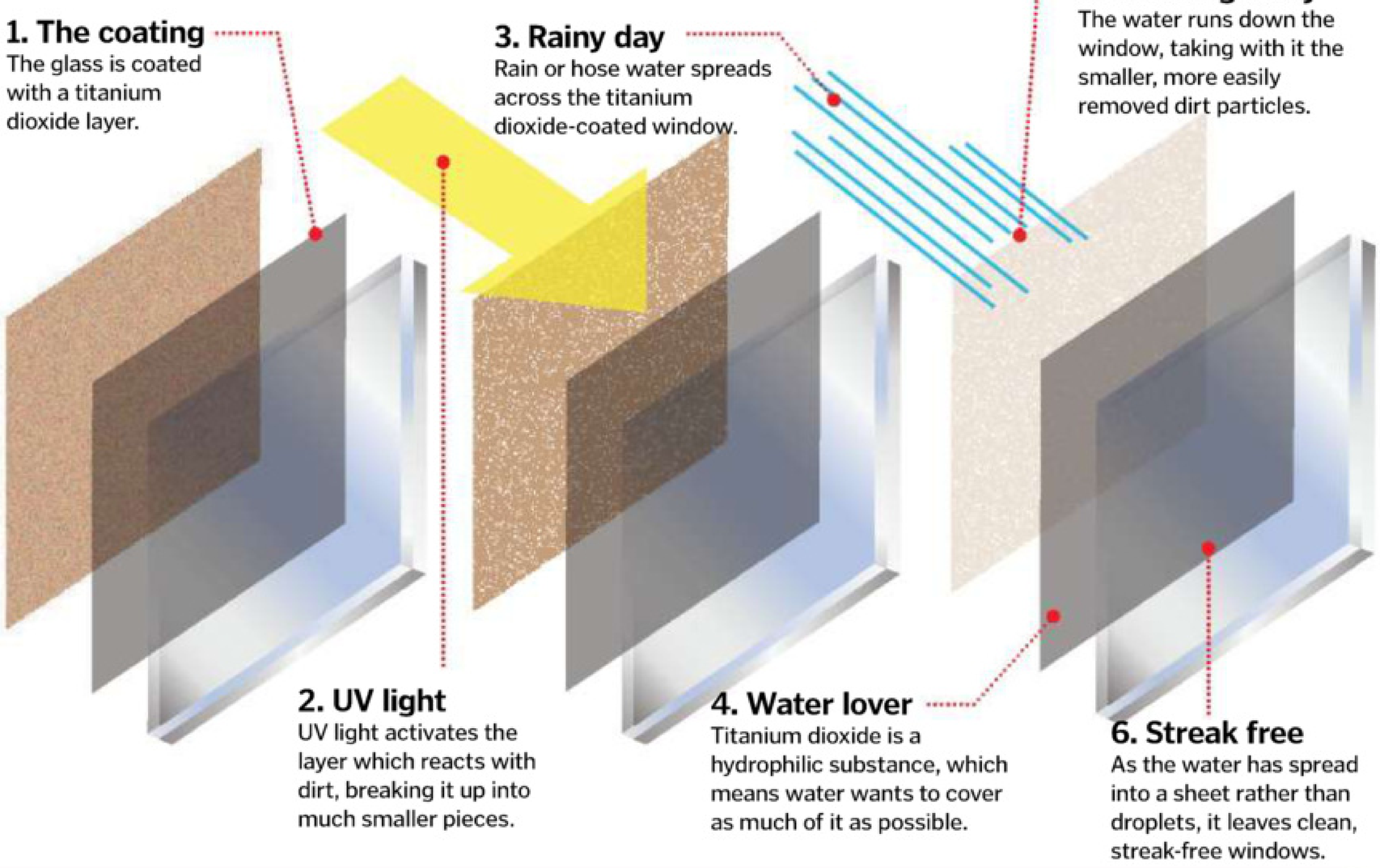
Inert medium
The roots grow down through rockwool, clay, vermiculite, sand or gravel – an inert medium providing structural support, not nourishment.

Drainage channels
These allow the nutrient solution to be drained out regularly, to stop it going stagnant and keep the roots oxygenated.

Self-cleaning glass explained

The technology that could spell the end for window cleaners

Cleaning windows can be an absolute chore, especially if they are high up. Luckily, a new invention on the market could mean the days of chamois leather, a bucket and a ladder are reduced to a distant memory. Glass is coated with a chemical compound of titanium dioxide that is activated by UV light. This compound reacts with dirt, breaking it down into tiny particles. This makes it much easier for the dirt to be washed off with just a quick blast of a hose. Even ordinary rain is enough to work away the smaller, looser dirt particles. This is because of the compound being hydrophilic, making water spread all over the surface, rather than streak down in droplets.



1. The coating
The glass is coated with a titanium dioxide layer.

2. UV light
UV light activates the layer which reacts with dirt, breaking it up into much smaller pieces.

3. Rainy day
Rain or hose water spreads across the titanium dioxide-coated window.

4. Water lover
Titanium dioxide is a hydrophilic substance, which means water wants to cover as much of it as possible.

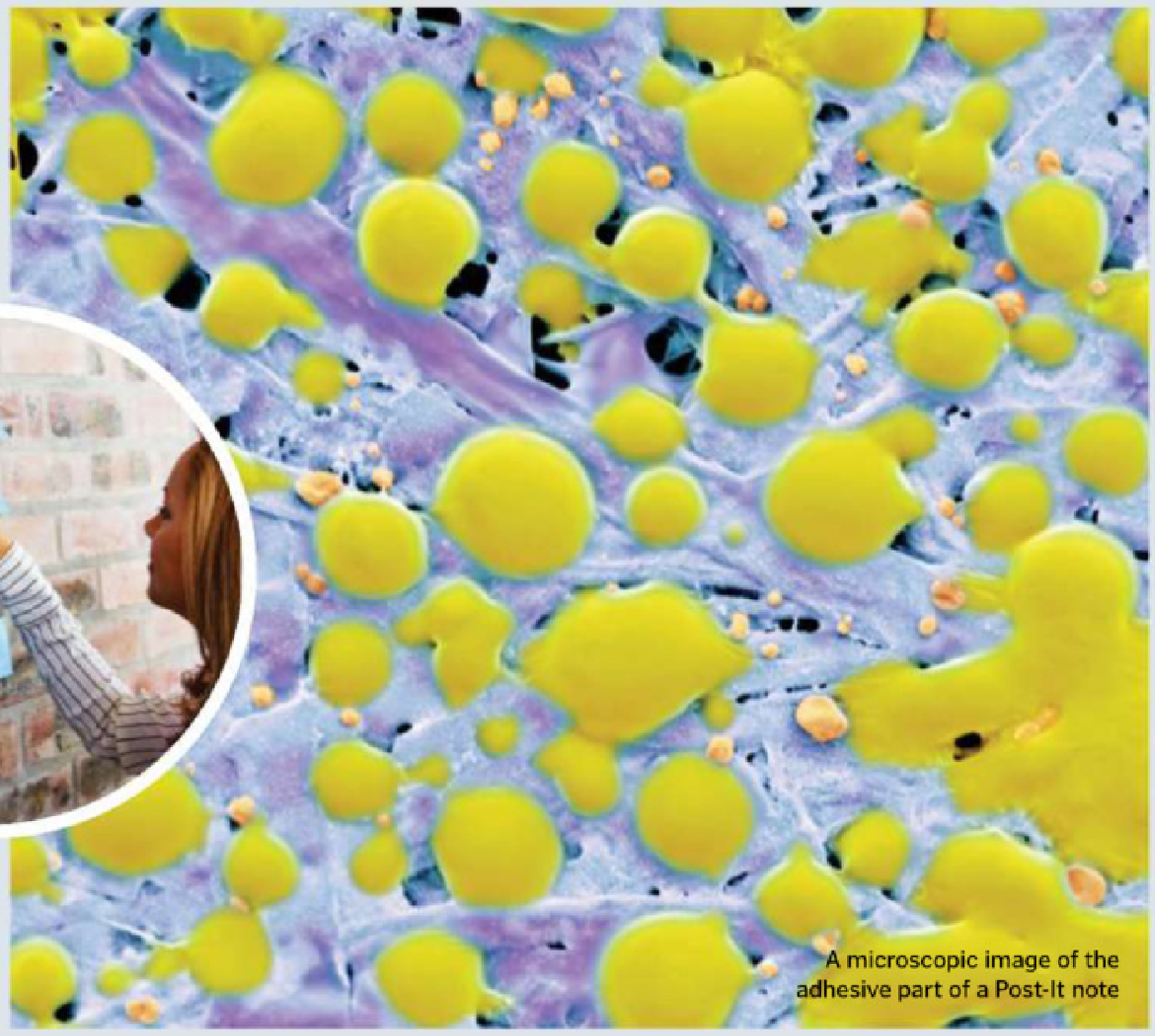
5. Washing away
The water runs down the window, taking with it the smaller, more easily removed dirt particles.

6. Streak free
As the water has spread into a sheet rather than droplets, it leaves clean, streak-free windows.

What's in a Post-It note?

The incredible science behind sticky paper memos

Each Post-It note has a strip of pressure-sensitive adhesive on the back. The adhesive enables notes to stick to a surface, but it does not bond too tightly so notes can be easily removed. The exact composition of Post-It adhesive is a closely guarded secret, but chemists who have studied it believe the glue contains microscopic bubbles. These bubbles rupture under pressure, creating tiny vacuums that act like suction cups to stick the note to a surface. The notes will continue to stick after multiple uses until all the bubbles have been burst so no further vacuums can form.



A microscopic image of the adhesive part of a Post-It note

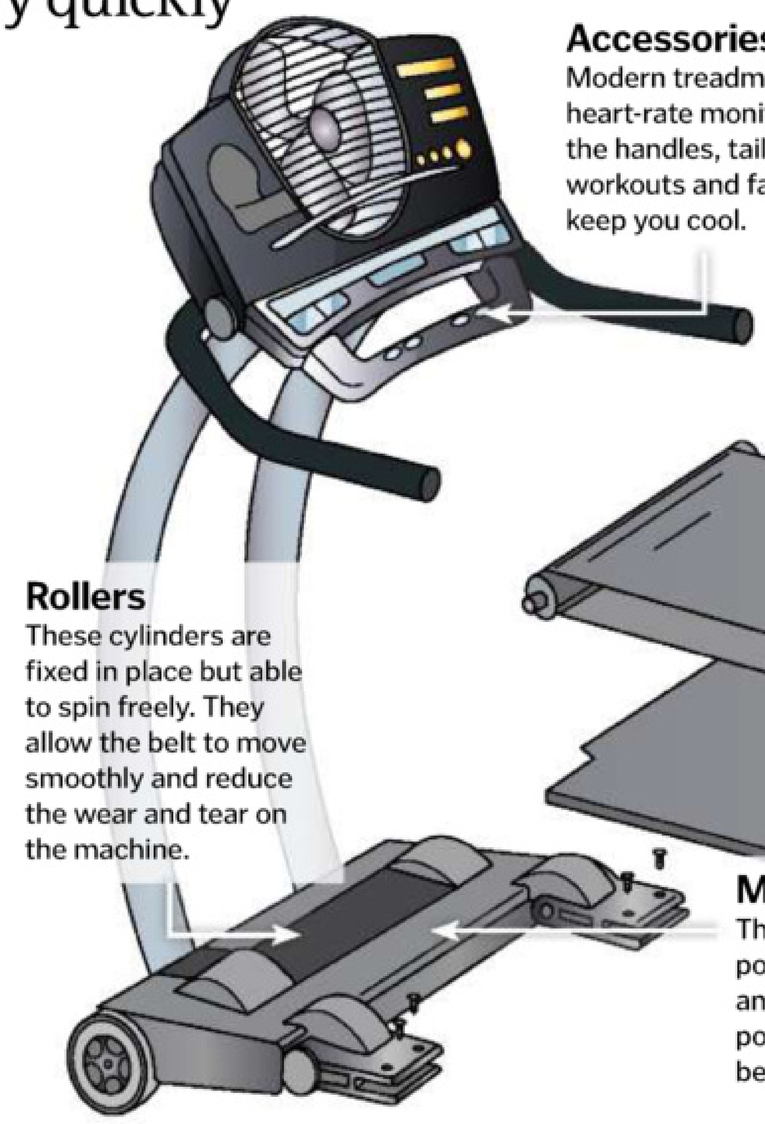
© Science Photo Library; Thinkstock

How treadmills work

How to go nowhere very quickly

In just 50 years, treadmills have evolved from a novelty item shown at trade shows to the staple of gyms and fitness rooms worldwide. Originally invented as a medical device for testing the cardiac health of patients, the treadmill was commercialised by William Staub, a Philadelphia-born engineer.

Staub was a fitness fanatic and developed the running machine in the late-1960s as a way of exercising without having to leave the house. Due to its practicality and relatively cheap price point he was selling 2,000 per year by the 1980s and 35,000 per year the following decade. The technology advanced, offering varied workout programmes, heart-rate monitors and emergency stop buttons.



Accessories
Modern treadmills have heart-rate monitors on the handles, tailored workouts and fans to keep you cool.

Belt
The top layer of the belt is made of PVC as it is springy yet durable. Beneath is a layer of cotton and polyester blend to reduce the sound of feet hitting the board.

Rollers
These cylinders are fixed in place but able to spin freely. They allow the belt to move smoothly and reduce the wear and tear on the machine.

Backing
Surrounding the belt is the deck. This will need to be of a sturdy material like steel to absorb the repeated pounding of feet.

Motor
The motor in a treadmill powers the belt around and around. It's not very powerful, usually only between 1.5 and 3hp.

Angle grinders are versatile tools – here's one serving as a power saw

Angle grinders explained

This DIY must-have can take on just about any job

Angle grinders are multi-purpose tools that can do almost everything, from polishing surfaces to shearing through steel. They can either be battery powered or work off the mains and consist of a powerful motor running a spinning disc, which is at a right angle to the handle.

If a wire brush is placed on the spindle, it becomes an excellent tool for removing dried mud or cement from a spade, acting like a high-speed brush.

Alternatively, a sharp-edged blade whirring at high speeds can easily slice through metal or score through tiles and stone. The rapid movement of the blade means the cut will be clean and smooth, rather than jagged and coarse, like a hacksaw cut would be.

They can also be fitted with a grinding wheel that, when run up and down a blade, can sharpen it by shearing off tiny slivers of metal. Angle grinders rotate at around 10,000rpm – ten times the speed of a normal drill motor – and you'll probably find one in nearly every DIY lover's shed.

© Thinkstock

KEY DATES
MOWING MILESTONES

1827
Edwin Budding brings out the first lawn mower, aimed at maintaining sports fields and big gardens.

1859
A new quieter version of the mower is released, which employs a chain rather than a roller to transfer power.

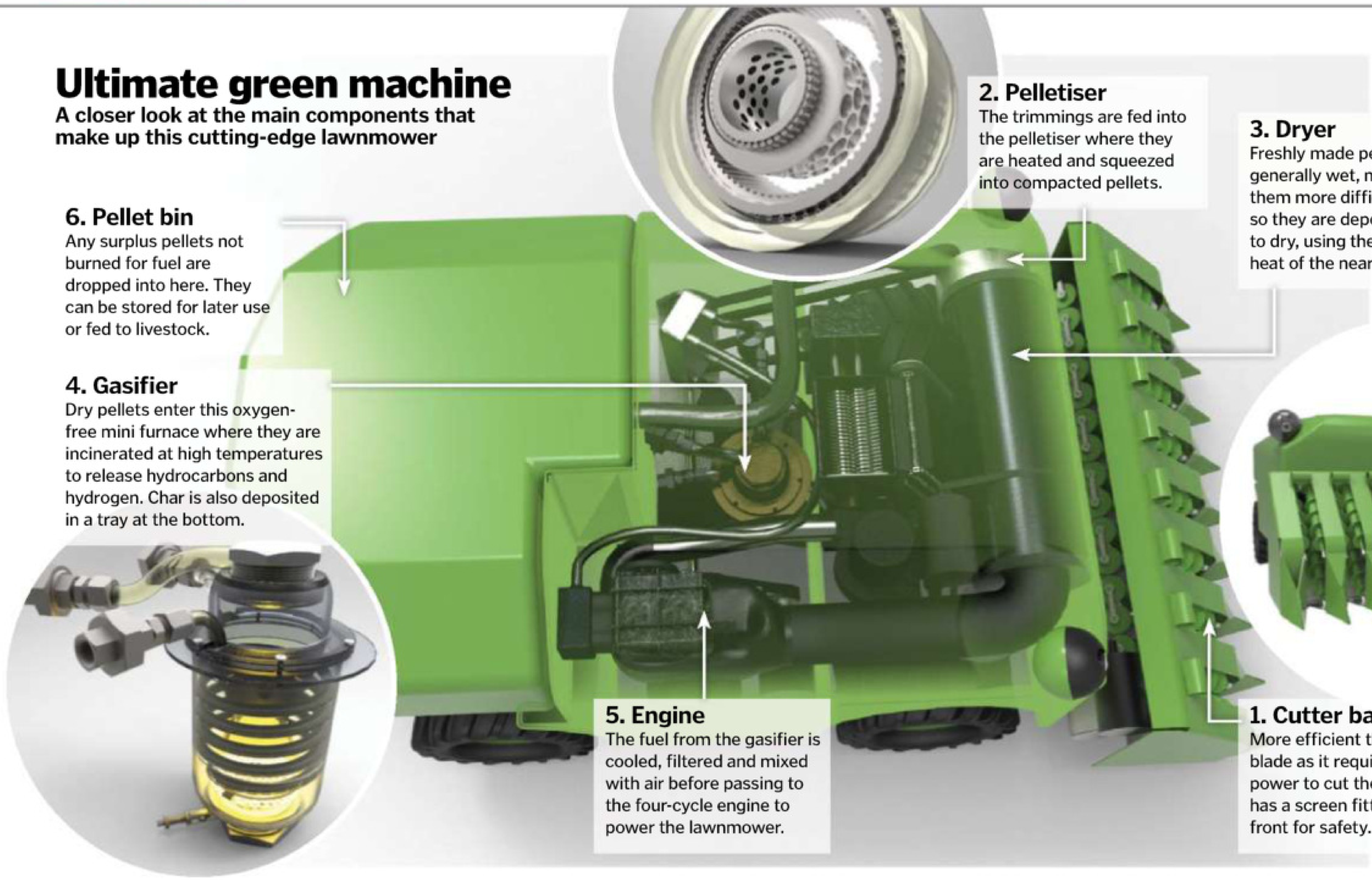
1893
James Sumner patents the first steam-powered lawn mower. Petrol-based mowers quickly follow.

1922
The first ever self-propelled ride-on grass-cutting tractor – called the Triplex – goes on sale in the USA.

1964
The first Flymo hover mower arrives, using a fan above the blade to generate a cushion of air.

DID YOU KNOW? *As well as being eco-friendly the EcoMow can navigate itself using GPS technology and on-board sensors*

Ultimate green machine
A closer look at the main components that make up this cutting-edge lawnmower



6. Pellet bin
Any surplus pellets not burned for fuel are dropped into here. They can be stored for later use or fed to livestock.

4. Gasifier
Dry pellets enter this oxygen-free mini furnace where they are incinerated at high temperatures to release hydrocarbons and hydrogen. Char is also deposited in a tray at the bottom.

2. Pelletiser
The trimmings are fed into the pelletiser where they are heated and squeezed into compacted pellets.

3. Dryer
Freshly made pellets are generally wet, making them more difficult to burn, so they are deposited here to dry, using the radiant heat of the nearby gasifier.

5. Engine
The fuel from the gasifier is cooled, filtered and mixed with air before passing to the four-cycle engine to power the lawnmower.

1. Cutter bar
More efficient than a rotary blade as it requires less power to cut the grass. It has a screen fitted to the front for safety.

Inside eco-mowers

Meet the 21st-century lawnmowers which have been designed to run off the very same grass cuttings we normally throw away

Invented in the 1820s, the earliest lawnmowers were surprisingly eco-friendly but fairly hard to operate, typically made out of heavy cast iron and with relatively small blades, although some agricultural varieties were bigger and used farm animals for pulling power.

By the time motorised versions rolled up decades later, this situation had reversed. The machines were easier to use but produced petrol fumes detrimental to the environment. Later electric models didn't generate pollution directly, but still relied on fossil fuels, and also came with the risk of electrocution.

Eco-mowers use 21st-century technology to get the best of both worlds: a mower that cuts the lawn by itself with super-green credentials. A cutter bar has replaced the traditional rotary blade, which consumes far more energy in order to keep it spinning. The grass then enters a pelletiser where the loose trimmings are compressed into pellets using a combination of heat and pressure.

The grass pellets then enter a small chamber to be dried and next comes the most crucial component of the eco-mower: the gasifier. Sealed off to prevent oxygen getting in, it subjects the dried-out pellets of grass to extreme temperatures (up to 1,250 degrees Celsius/2,282 degrees Fahrenheit). In a process known as pyrolysis the biomass releases hydrogen and other hydrocarbons, which, along with air, can then be fed into the engine.

All that's left over from pyrolysis is carbon char, which is by no means waste either, as ongoing research is revealing an ever-wider range of applications for it. This includes compression into charcoal briquettes, water treatment and even improving soil quality on overused agricultural land.

© E-Mow/ecomowtech.com

Waste power
Grass trimmings are not the only waste product generating power around the world today. Used vegetable oil (UVO) from factories and fast-food restaurants can be processed and used as an alternative to diesel in cars and public transport. In Norway, tons of household rubbish are being incinerated to heat water and generate electricity for areas of Oslo. Perhaps most surprising of all, though, are pioneering projects (like one in Ghana) that are converting sewage into reusable products – including fertiliser and biofuel. It also means less sewage is being dumped into the ocean.

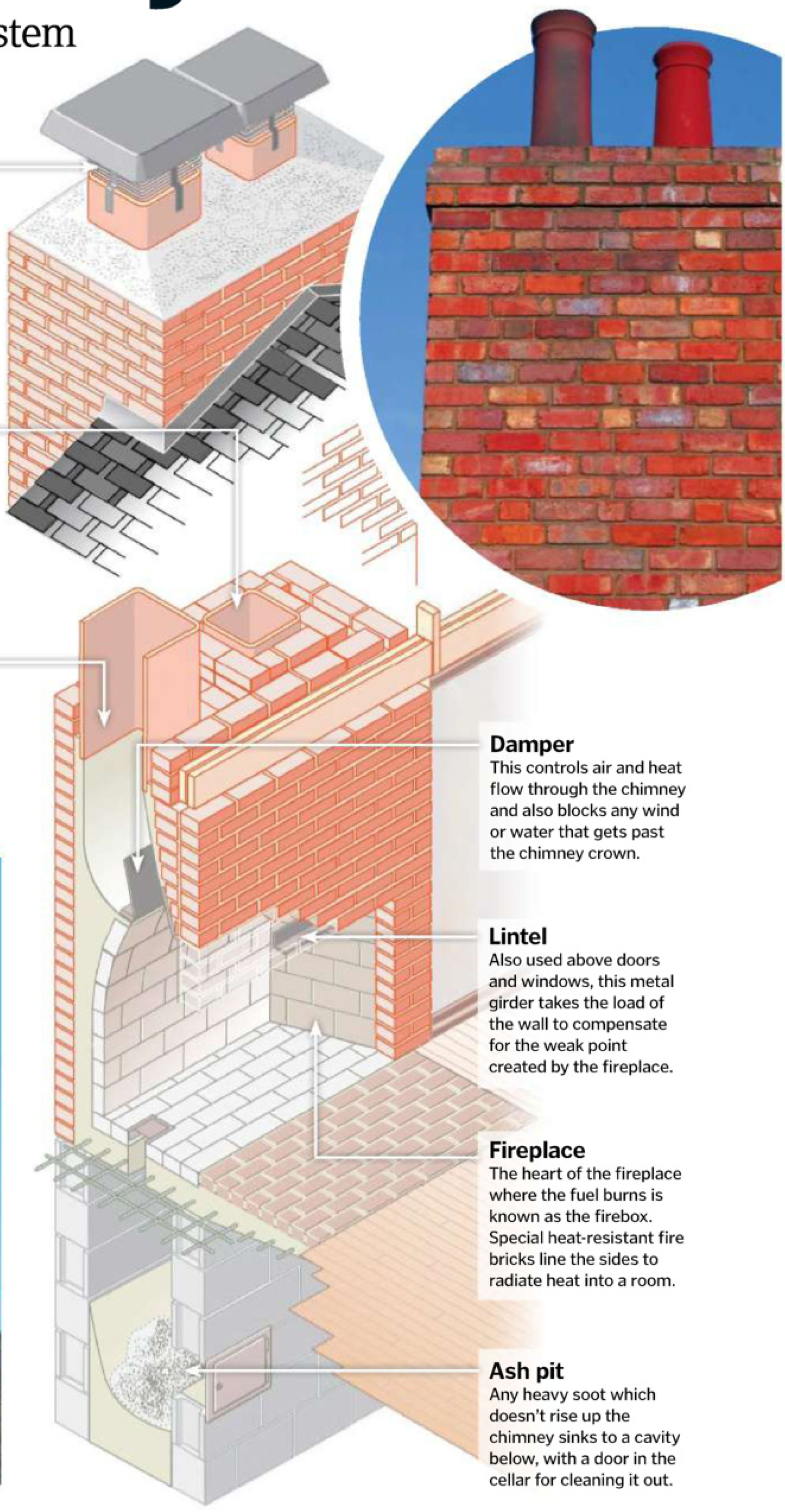
How do chimneys work?

Inside the classic household heating system

The fact that hot air is less dense than cold and so rises is vital to the workings of a chimney. In order to vent fumes out of our homes, they rely on a number of scientific principles to work effectively. Thanks to convection currents, pressure differences help fluids – in this case waste gases – move from the fireplace to the roof. This is known as the Venturi effect. Think of the hot fumes as water in a hosepipe. When the tap is turned on, water being forced through the narrow tube increases its speed; the same applies in a chimney.

The stack effect also helps speed up the process and works when surrounding cold air is denser than the hot air inside. This ensures that the hotter air always rises. Taller chimneys are more efficient as a higher column of air can build up; around 4.6 metres (15 feet) is considered an ideal height.

On a wider scale than the chimney, every house contains a neutral pressure plane (NPP). Air pressure above this level is higher than outside (positive) and tries to force its way out, while everything below is negative, so air is drawn in. By putting chimneys on the roof we ensure the exit point is as far above the NPP as possible so smoke doesn't sink back into the room, though sometimes high winds counteract this pressure differential.



On the roof
Vents raised off the roof emit the smoke away from the building, while chimney caps stop water, birds or other large debris getting in.

Flue #2
A second flue deals with fumes from the boiler or another fireplace. Dividing the flues helps to reduce creosote buildup.

Flue #1
Smoke and hot air naturally travel upwards from the fireplace. Flue efficiency is increased by the Venturi effect and draught.

Damper
This controls air and heat flow through the chimney and also blocks any wind or water that gets past the chimney crown.

Lintel
Also used above doors and windows, this metal girder takes the load of the wall to compensate for the weak point created by the fireplace.

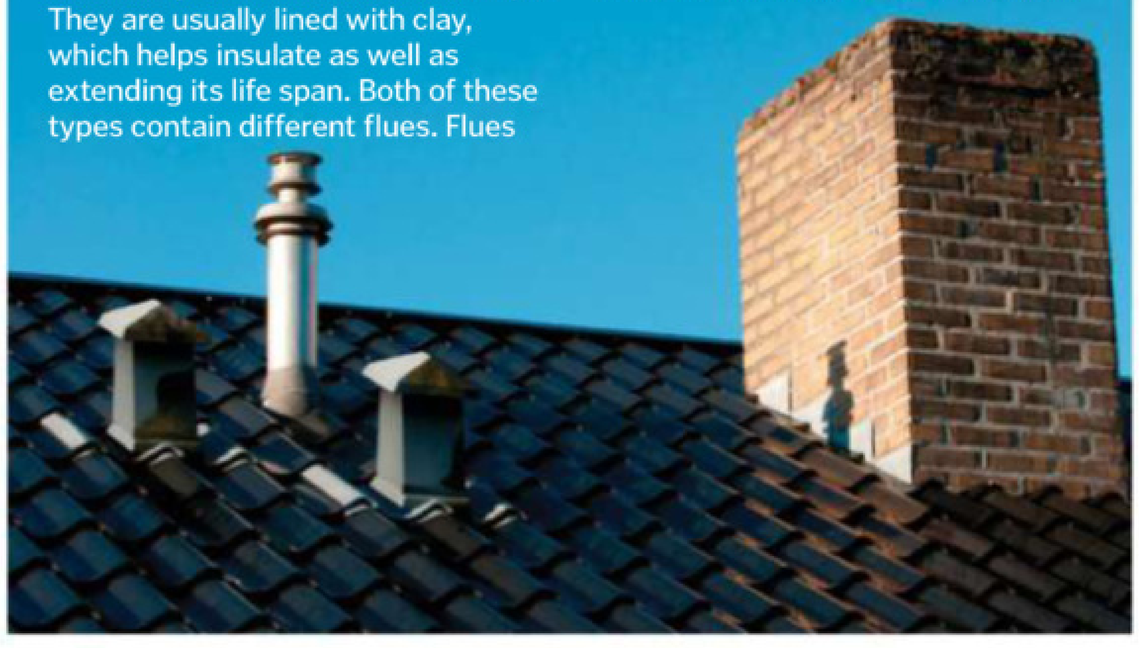
Fireplace
The heart of the fireplace where the fuel burns is known as the firebox. Special heat-resistant fire bricks line the sides to radiate heat into a room.

Ash pit
Any heavy soot which doesn't rise up the chimney sinks to a cavity below, with a door in the cellar for cleaning it out.

Chimneys big and small

Chimneys come in all shapes and sizes. Metal variations are quick to install and have push-fit joining so are more versatile and adaptable than their brick equivalents. Made of stainless steel, they are most suitable for coal and wood fires.

Brick chimneys are the type most commonly seen on Britain's rooftops. They are usually lined with clay, which helps insulate as well as extending its life span. Both of these types contain different flues. Flues help retain heat and expel toxic gases. Masonry versions usually have what is known as 'class one.' This is a basic system that relies on the natural rising of the hot air to work. However, the steel variety uses a 'class two', which is a more complex series of pipes. These can either be metal or a small brick vent.



RECORD BREAKERS
CHIP CHAMP

83HRS

FRENCH FRY COOKATHON

Belgian chef Chris Verschueren cooked and served a staggering 15,000 portions of french fries in just 83 hours, taking only a 100-minute break for a shower during the shift.

DID YOU KNOW? *Don't feel guilty about using your fryer; some oven chips actually have more fat than deep-fried chips!*

Deep fryer technology

Cooking the perfect chips requires oil at scorching temperatures, but how do deep fat fryers get so hot and yet remain safe to use?

Deep fat fryers operate at an average temperature of 185 degrees Celsius (365 degrees Fahrenheit), and have a reputation as dangerous kitchen appliances that start fires, but modern equipment has sophisticated technology to both keep the oil hot and protect the cook from potential risks.

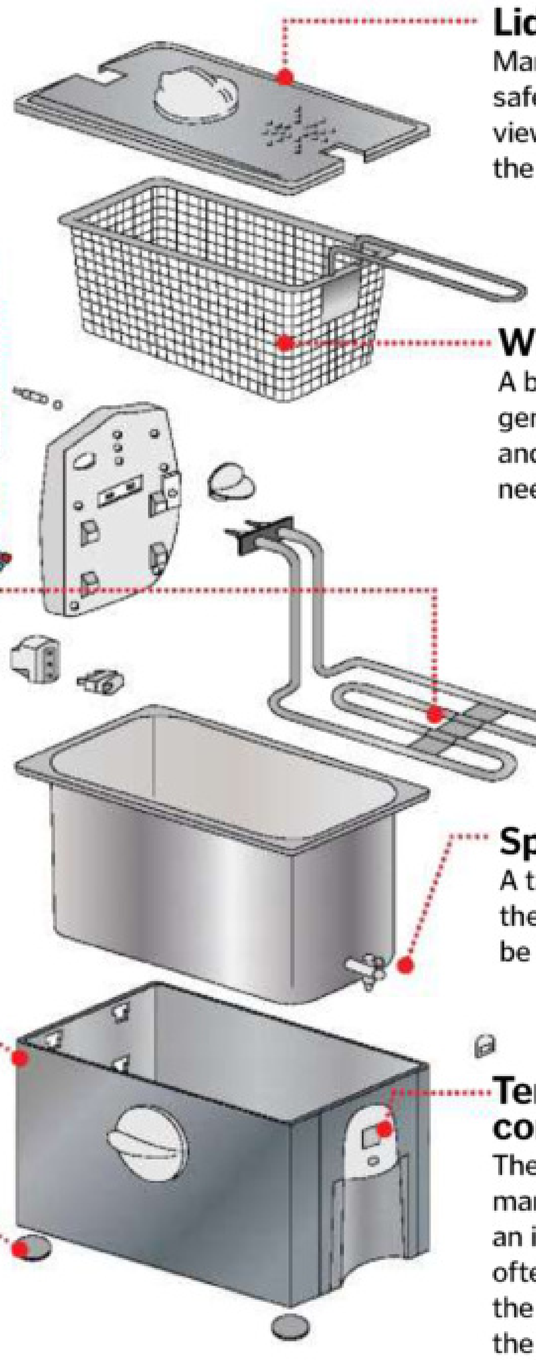
The most important component of the fryer is the mechanism which heats the oil: this can be gas or electric. In an electric fryer a heating element is immersed in the oil, and as an electric current passes through it, resistance generates heat, which is transferred to the oil.

In contrast, gas fryers use gas burners underneath the vat of oil to generate heat. Though these warm up more rapidly, any food particles that sink to the bottom are easily burned, tainting the oil's taste. Gas fryers will often have a 'cool zone' – a dip in the base of the fryer extending below the burners; remaining cooler. Sinking particles drop into this recess.

Many oils will ignite at 260 degrees Celsius (500 degrees Fahrenheit), so modern fryers often incorporate a microchip which shuts off the power should the oil begin to overheat. Many new fryers also have a thermostat that senses and adjusts the temperature, keeping it at optimum heat level.

Electric fryer inside and out

A look at the inner workings of this popular cooking appliance



Lid
Many fryers have a locking safety lid with a clear viewing window to protect the user from spitting oil.

Wire basket
A basket allows food to be gently lowered into the oil and removed without the need for utensils.

Automatic shutdown
The power will automatically cut out if the oil begins to overheat, preventing it from reaching the temperature at which it might catch fire.

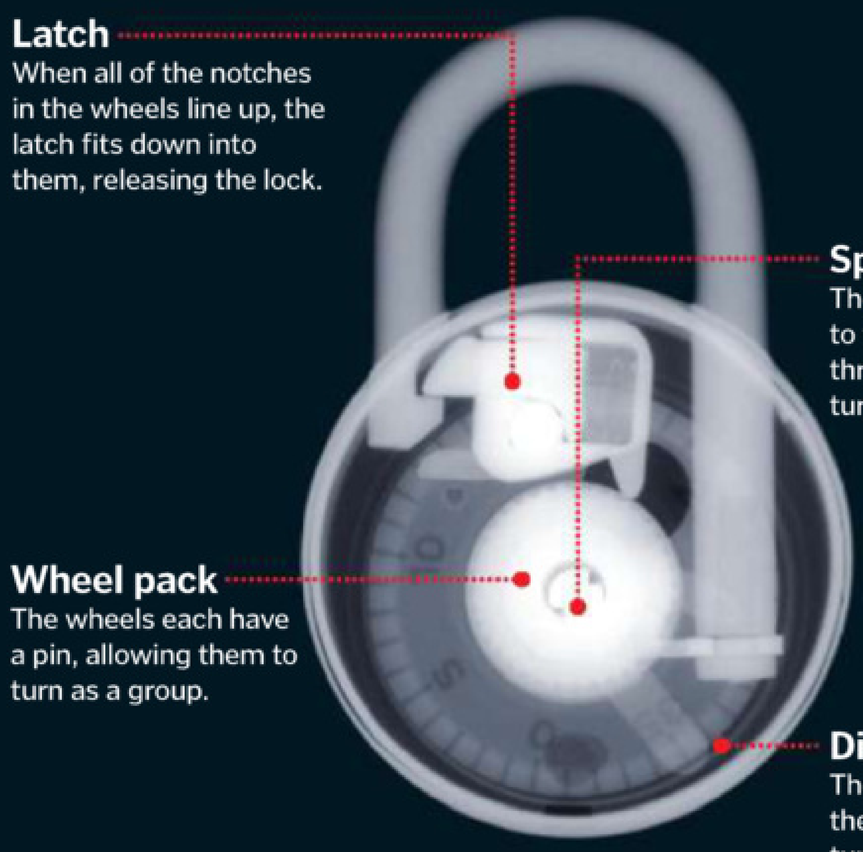
Heating element
Electric fryers use an element to heat the oil. The electric current encounters resistance as it moves through the element, generating heat.

Spigot
A tap on the bottom of the tank allows used oil to be drained easily.

Insulated casing
The shell of the fryer is often made of plastic, insulating the unit and preventing burns even when the oil is hot.

Temperature control
The temperature can be manually adjusted, but an internal thermostat is often also used to keep the oil temperature within the ideal range.

Rubber feet
Sticky rubber feet on the bottom of the fryer prevent it from slipping on or burning the work surface.



Latch
When all of the notches in the wheels line up, the latch fits down into them, releasing the lock.

Spindle
The spindle is attached to the dial and runs through the wheels and turns the drive cam.

Wheel pack
The wheels each have a pin, allowing them to turn as a group.

Dial
The external dial moves the drive cam, which in turn spins the wheels.

Combination locks

Discover what is going on at the heart of these traditional security devices…

A combination lock has three notched wheels, which must be lined up to release the latch. The wheels have pins on either side so during rotation one will 'catch' the next.

To open it, the dial is turned clockwise for two rotations – this moves the first wheel, which spins until its pin comes into contact with the second. When the pins collide, the first wheel rotates the second, which picks up the third.

Continuing to turn clockwise to the first number lines the notch on the third wheel up with the latch. The dial is then twisted anti-clockwise, pushing the first and second away from the third wheel's pin. The notch on the second is lined up with the latch and the dial turns clockwise again, moving the first to its position and the lock opens.

© Getty; Thinkstock; SPL

The impact of a nail gun

Meet the nail-slinging power tool putting hammers out of business

Used to drive nails into walls and other surfaces, the nail gun is an automated rival to the manual hammer in many areas of construction and manufacture. Its ability to launch nails at high speed and with relative ease makes the simple hammer seem pretty primitive by comparison.

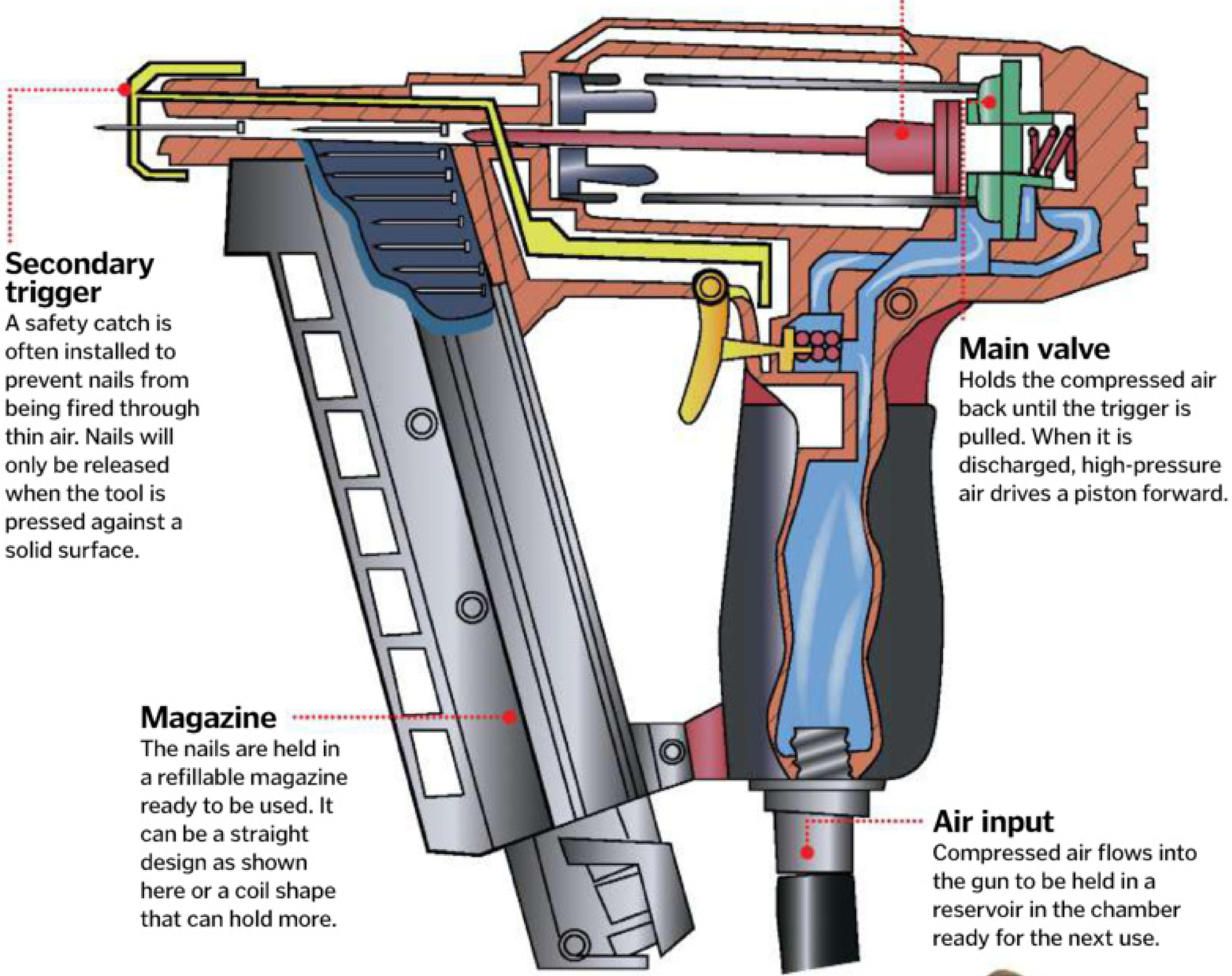
First invented in the 1950s, today there are a range of different nail guns on the market. The most basic is the spring-loaded design. This variation holds one nail at a time and uses a coiled spring to deliver the nail into the desired surface upon the press of the trigger.

Another type is the solenoid – or electromagnetic – nail gun. In this case, the piston is made from a magnetic material, which is either forced out of or drawn into the gun, depending on which way the magnetic current is flowing. Solenoids are more reliable than the spring-loaded design but have a lot less power than pneumatic nail guns (see annotation).

Using compressed air generated from pistons, a pneumatic nail gun can penetrate even the hardest surfaces. Another variation is the combustion nail gun, which ignites flammable gas mixed with air to create a small explosion (like those that power your car engine) forcing the nail out of the chamber. These guns combine power with portability as there is no neeed for an air compressor attachment.

Inside a pneumatic gun

Discover the inner workings of an air-powered nail gun



Piston
The piston shoots forward and propels the nails fed from a magazine in front.

Secondary trigger
A safety catch is often installed to prevent nails from being fired through thin air. Nails will only be released when the tool is pressed against a solid surface.

Main valve
Holds the compressed air back until the trigger is pulled. When it is discharged, high-pressure air drives a piston forward.

Magazine
The nails are held in a refillable magazine ready to be used. It can be a straight design as shown here or a coil shape that can hold more.

Air input
Compressed air flows into the gun to be held in a reservoir in the chamber ready for the next use.

Nail guns can save a lot of time and energy compared to hammering

Origins of the nail gun

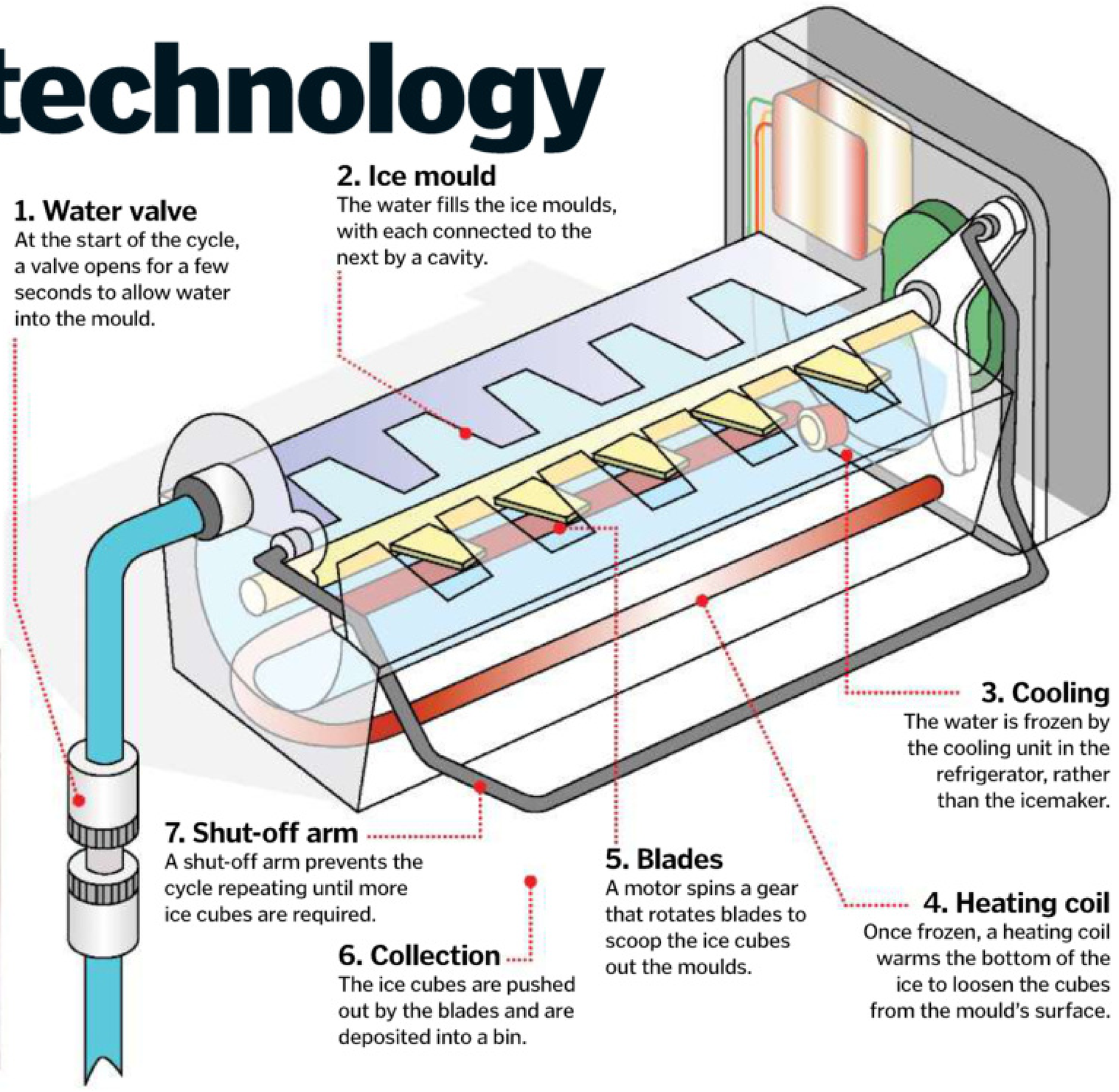
The tool was first invented in the 1950s by three US construction workers – Marvin Hirsch, John Ollig and Reuben Miller – who are thought to have based their idea on the mechanisms of WWII machine guns.

Veterans of the war, they devised the product in a garage and displayed their idea to the Independent Nail Company. Impressed by their invention, the company offered the trio $25,000. They initially declined the offer with a view to starting up their own business, but after running into financial difficulties, the rights were eventually purchased by another firm, Bostitch. Over the following decades, it evolved into the widely used power tool we know today.

Icemaker technology

How do these machines produce ice cubes in bulk to keep our drinks cool?

Icemakers are essentially a conveyor belt of ice cubes made for instant use. They come in a variety of shapes and sizes for different purposes, but almost all use the method of freezing water in a mould and then heating it slightly so the ice cubes slide out with ease. Here we look at how a conventional icemaker built into a domestic fridge-freezer works, like the one pictured below.



1. Water valve
At the start of the cycle, a valve opens for a few seconds to allow water into the mould.

2. Ice mould
The water fills the ice moulds, with each connected to the next by a cavity.

3. Cooling
The water is frozen by the cooling unit in the refrigerator, rather than the icemaker.

4. Heating coil
Once frozen, a heating coil warms the bottom of the ice to loosen the cubes from the mould's surface.

5. Blades
A motor spins a gear that rotates blades to scoop the ice cubes out the moulds.

6. Collection
The ice cubes are pushed out by the blades and are deposited into a bin.

7. Shut-off arm
A shut-off arm prevents the cycle repeating until more ice cubes are required.

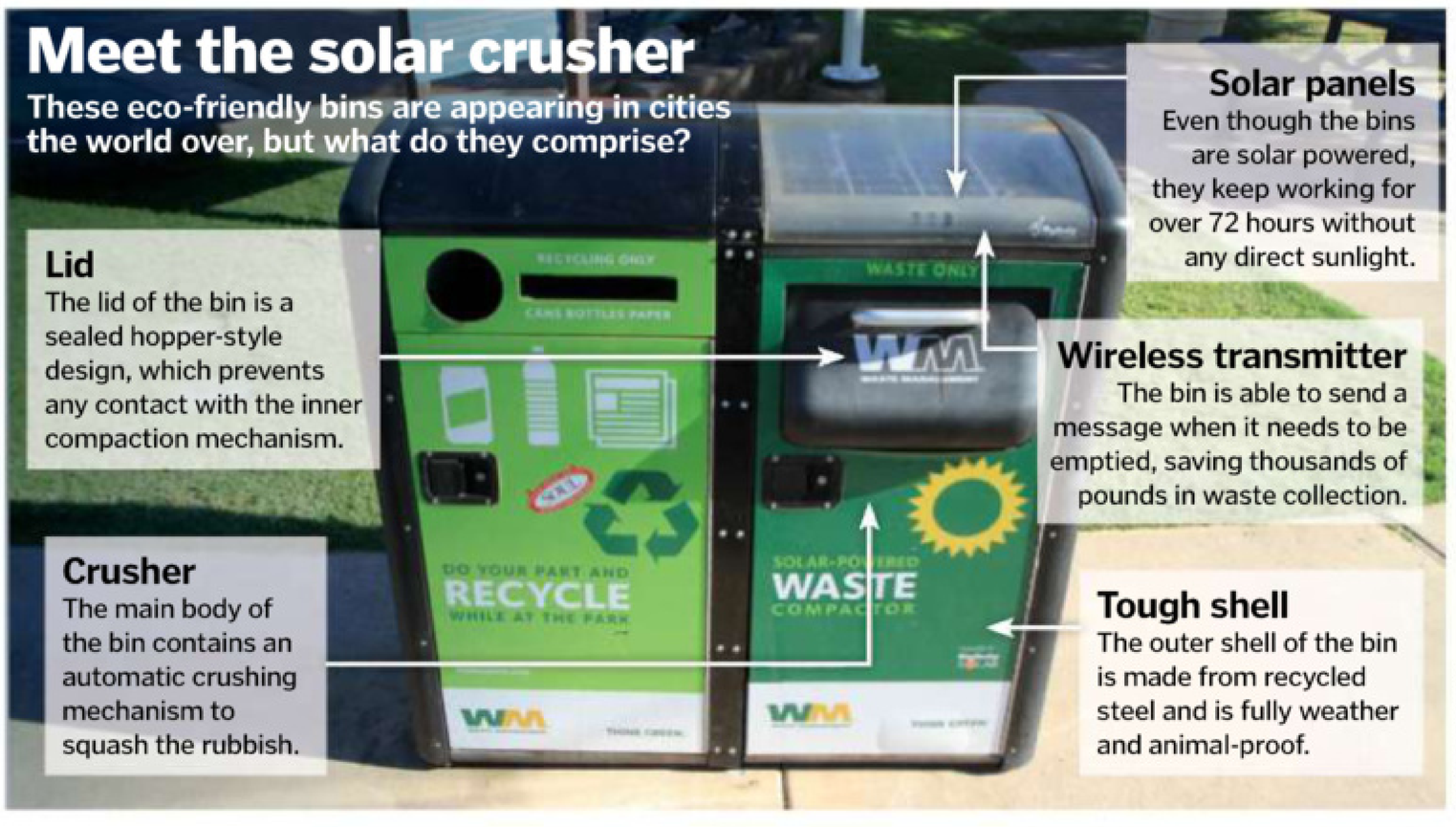
Solar-powered rubbish bins

They crush our litter, send an email when they are nearly full and are powered entirely by the Sun – but what tech makes these trash cans so sophisticated?

Solar-powered bins contain a sensor to detect when they're full. When litter reaches the sensor, an internal compaction mechanism is activated, crushing the rubbish. The bins can hold up to eight times more refuse: a capacity of 800 litres (180 gallons).

The compaction mechanism runs on a 12-volt battery and does not use hydraulic fluid, so requires very little power. This enables the bins to be used in areas that receive little sunlight; in fact, they can even work in the shade – most need eight hours of sunlight a month for the compactor and internal components.

Many solar-powered bins include a sensor connected to a wireless cellular data transmitter, which sends a signal to local waste disposals when the bin is 85 percent full, making the collection process more efficient.



© Thinkstock; Alamy

Homes of the future

Now that smartphones are everywhere, get ready for the smart home!

We've all been there. Halfway to the airport and suddenly gripped by the unshakable fear that we've forgotten to switch off the oven or lock the windows. With a smart home, you can put your mind at rest and fix any little oversights, all from your phone as you speed toward your flight.

In a smart home, all the electronic devices are connected to one another in one controllable network, allowing inhabitants to interact with their homes like never before and offering greater comfort, convenience, personalization, energy savings and opportunities for fun!

Want your coffee maker to crank up downstairs as soon as you throw back your sheets? A smart home will let you arrange that. Want to start the bread maker churning and the pool heating as you leave the office? You can do that too. Want your home to learn your habits and help cut your energy consumption, or to notify you if it senses anything untoward like an intruder? No problem at all.

The basis for all these technological advances is the 'Internet of Things' – the exponentially expanding web of devices that are connected to the internet, allowing them to talk to each other and to you, transforming the way we live.

5 TOP FACTS
SMART HOME STARTER KITS

Smart socket

1 For just £40 ($67), the Belkin WeMo switch transforms ordinary electronic devices into smart gadgets you can control and schedule from your phone.

Leading light

2 A LIFX LED smart bulb might set you back £80 ($135), but will reward your investment with 27 years of kaleidoscopic colour and smart functionality.

Thoughtful thermostat

3 By learning and adapting to your schedule, the Nest Learning Thermostat should pay for its £180 ($300) price tag within a couple of years in most UK households.

Smoke signal

4 Smoke and CO detector Nest Protect will talk to you before howling, so you can deactivate it, discard your burnt toast and save face. Not bad for £90 ($150).

Security surveillance

5 The Canary home security system, available soon for about £120 ($200), is a pint-sized surveillance unit that alerts your phone if it detects unusual activity while you're out.

DID YOU KNOW? *The USA's smartest home is owned by SmartThings CEO Alex Hawkinson and includes over 150 connected devices*

Surveillance unit
Live video sent to your phone puts your mind at rest while at work or on holiday.

Smarter slumber
Bed tracks your sleep cycles and sleep quality, activating the coffee maker at the first signs of waking.

Sun shades
Open and close automatically according to the amount of direct sunlight.

Smart thermostat
Saves you money on energy bills by learning your habits and cranking down automatically while you're gone.

Washing machine
Can delay start until energy prices are cheapest, and will text you when laundry cycle is complete.

Intelligent fridge
Enters sleep mode while you're out of town, suggests recipes based on contents and alerts you of low inventory or expiring items.

Talking to your tech

Tracking the growth of the Internet of Things

20% NUMBER OF USA ADULT INTERNET USERS WHO ALREADY OWN A DEVICE THAT CONNECTS THE PHYSICAL ENVIRONMENT TO THE INTERNET [FORRESTER]. THIS WILL RISE TO 50% BY 2020 [PARK ASSOCIATES]

1.5 million NUMBER OF FULL HOME AUTOMATION SYSTEMS INSTALLED IN THE USA IN 2012 [ABI RESEARCH]

224 million NUMBER OF HOMES WORLDWIDE (1 IN EVERY 8.5 HOMES) THAT WILL HAVE SOME SORT OF SMART HOME TECHNOLOGY INSTALLED BY 2019 [STRATEGY ANALYTICS]

10% NUMBER OF US HOMEOWNERS AGED 25-34 WHO OWN AT LEAST ONE SMART ENERGY DEVICE [PARK ASSOCIATES]

1 in 9 (11%) NUMBER OF UK HOUSEHOLDS THAT WILL BE USING AT LEAST ONE SMART DEVICE BY THE END OF 2014. THIS NUMBER WILL JUMP TO OVER 1 IN 4 (27%) JUST FIVE YEARS FROM NOW [STRATEGY ANALYTICS]

$7.8 billion (£4.6 BILLION) PREDICTED SIZE OF THE DIY SMART HOME MARKET BY 2019, UP FROM $1.3 BILLION (£770,000) TODAY [NEXTMARKET INSIGHTS]

150 NUMBER OF INTERCONNECTED DEVICES IN USA'S 'SMARTEST' HOME [HUFFPO VIDEO INTERVIEW WITH OWNER]

20% AMOUNT AN AVERAGE USER COULD SAVE ON THEIR ENERGY BILL BY INSTALLING A NEST LEARNING THERMOSTAT [NEST]

7% THE NUMBER OF US HOMES WITH PROGRAMMABLE THERMOSTATS JUMPED BY THIS MUCH BETWEEN 2012 AND 2013 [CONSUMER ELECTRONICS ASSOCIATION]

£234 OR $393, AVERAGE TECHNOLOGY SPEND OF UK SMART-HOME OWNERS, LESS THAN HALF THAT OF THEIR US EQUIVALENTS (£517 / $868) [STRATEGY ANALYTICS]

Homes of the future

Automated home electronics have been on the scene for decades, but only recently have they been able to begin talking to one another and functioning in concert. That's largely thanks to the advent of efficient low-cost wireless protocols – think Wi-Fi, Bluetooth, mobile phone networks – in the early-2000s, which use radio waves to transmit messages wirelessly.

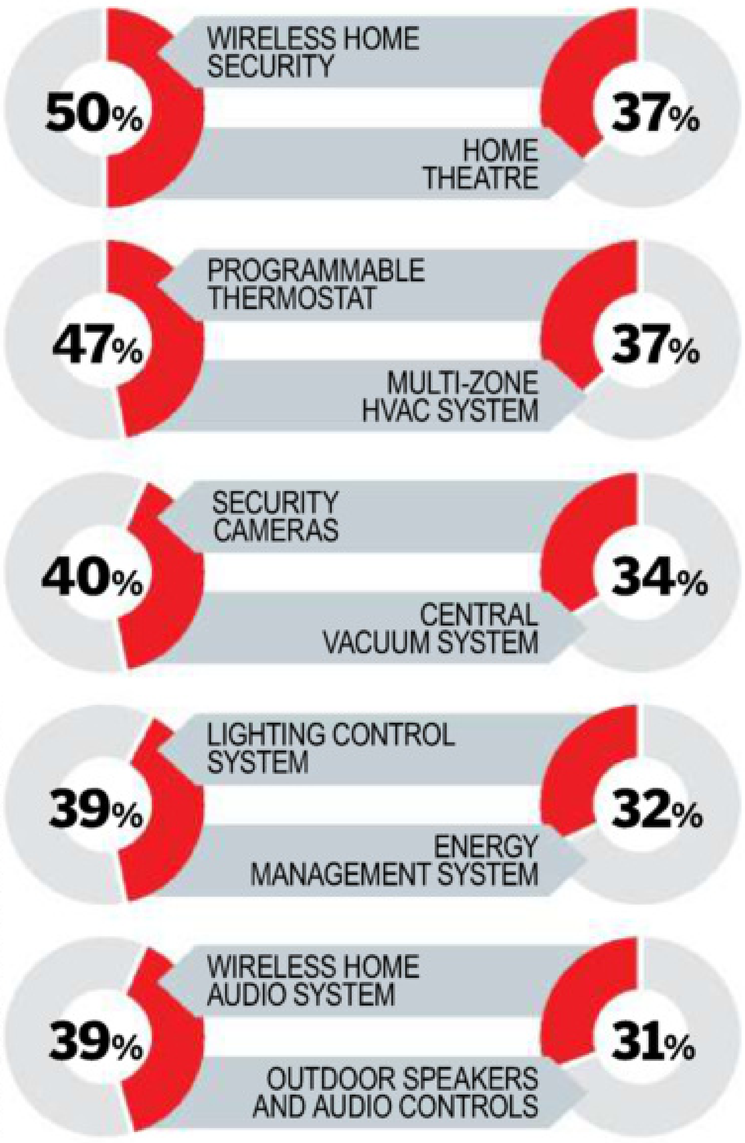
ZigBee and Z-Wave are similar protocols that can be thought of as low-power, short-range versions of Wi-Fi. They are ideal for use inside the smart home because they're optimised for transmitting small amounts of data – like messages to and from smart devices – through walls and furniture, over the range needed for a typical household.

Smart devices are connected via these wireless networks to a central hub where they can be controlled with a tablet or smartphone. They can also be programmed to carry out any action based on the logic command 'If This Then That', or IFTTT (rhymes with lift). IFTTT lets you dictate what action a device should take for a given stimulus.

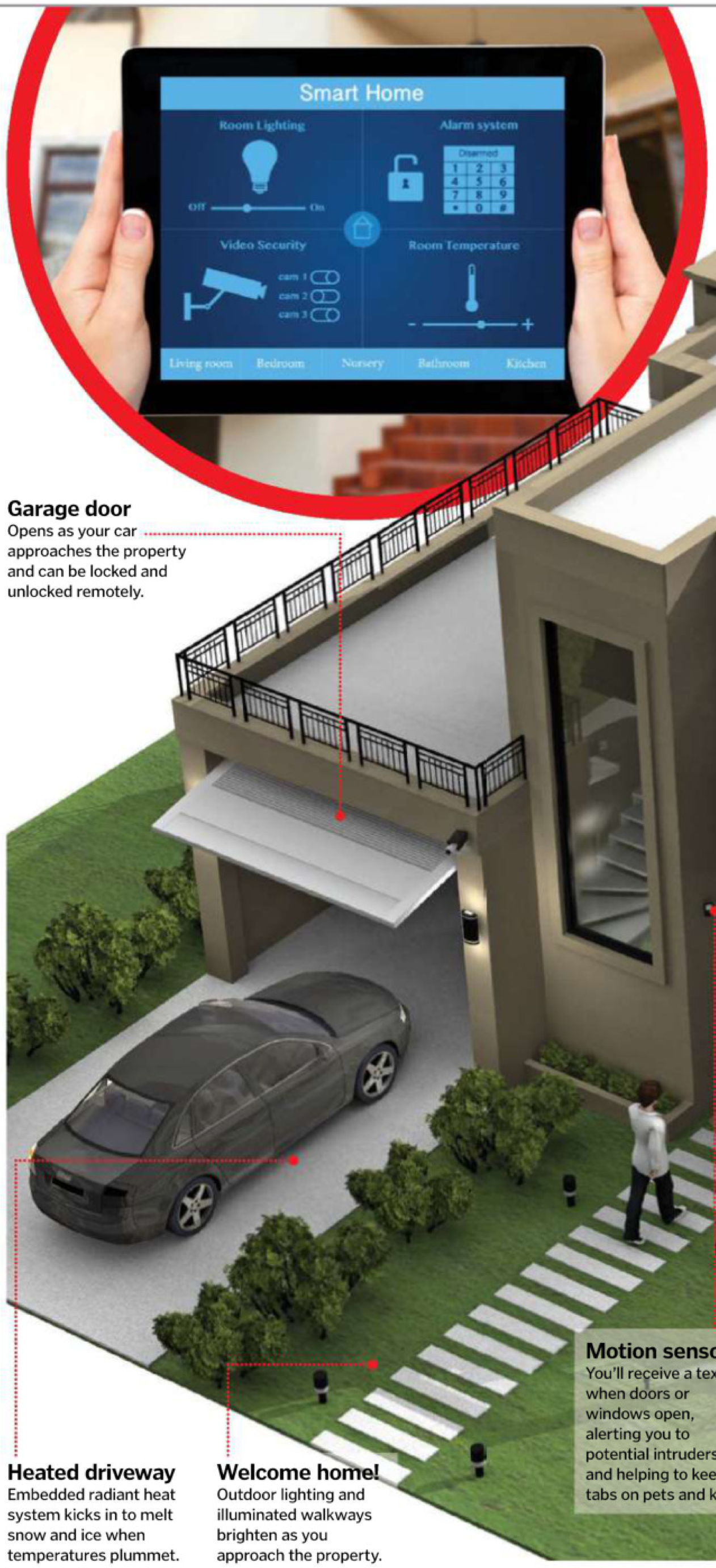
For example, announcing to your TV, "It's movie time", might lower the shades, dim the lights, activate your surround sound system and fire up the popcorn maker. Now that's smart.

Homeowner wish list

Top ten most coveted smart technologies*



*data from National Association of Home Builders



Smart locks
Grants keyless entry to family members and guests with time-restricted access codes – handy when struggling with groceries!

Garage door
Opens as your car approaches the property and can be locked and unlocked remotely.

Motion sensors
You'll receive a text when doors or windows open, alerting you to potential intruders and helping to keep tabs on pets and kids.

Heated driveway
Embedded radiant heat system kicks in to melt snow and ice when temperatures plummet.

Welcome home!
Outdoor lighting and illuminated walkways brighten as you approach the property.

RECORD BREAKERS
SMART MANSION

$120 MILLION

MOST VALUABLE SMART HOME

Bill and Melinda Gates's Pacific lodge-style smart mansion in Medina, USA, is nicknamed Xanadu 2.0 after the title character's estate in *Citizen Kane*.

DID YOU KNOW? *X10, a wired connection system made in 1975, was one of the earliest smart-home systems and is still in use today*

THE SMART OUTSIDE

Sprinklers
Override their program to turn off when it rains and on if the soil becomes too dry.

Pool party
Water temperature can be set on your drive home, ready for your evening dip.

Attentive awnings
They adjust themselves automatically as the Sun moves overhead.

Surveillance system
Keeps an eye on the kids in the pool, and knows the difference between pets and an intruder.

Occupied home simulator
Activates lights and shades to give an impression of habitation while you're away on holiday.

Homes of the future

Until recently, smart homes have mostly been viewed as quirky playgrounds reserved for the super-rich and diehard *Jetsons* fanatics. In the US today, less than one per cent of homes have a full automation system installed, but the picture is changing rapidly. Why?

"What's happening is there's a shift from that past market – which required a professional installer, and more recently a service-provider subscription – to what we're starting to see now: the roll-out of what we call DIY smart homes", explains chief analyst and smart-home expert Michael Wolf of NextMarket Insights in Seattle.

The majority of new smart objects are designed to plug-and-go. New smart-home residents can shop around for devices that best meet their needs, download the apps that make them run, stitch them all together through their humble smartphone, and save themselves a fortune in the process. "That's where we see the potential for much greater adoption, because the barriers in terms of cost and heaviness of the install start to go down", says Wolf.

In 2014, tech giants have rushed to make their first forays into the smart-home market, steering it firmly toward the mainstream. In January 2014, Google acquired Nest Labs – founded by iPod designer Tony Fadell – for £1.9 billion ($3.2 billion). Nest's most popular product, the Learning Thermostat, responds to your routines and preferences, turns itself down when it notices you're away, helping you save energy.

Elsewhere, Microsoft formed a partnership with smart hub and device company Insteon in May, and in June Apple announced that its own Siri-integrated smart-home platform HomeKit would debut as part of the upcoming iOS 8 release this autumn.

So if smart homes offer improved comfort, convenience, security and environmental credentials, for an affordable price, what's the catch? For one thing, the explosion of new products, all running on different protocols, can be hard to integrate; less tech-savvy consumers might want to hold off a year or so while the industry reaches a better consensus.

More troubling is that smart homes, like any internet-connected device, are potentially hackable. What if a burglar finds a way to open your smart lock and disable your intelligent security systems? Others worry that products like Nest give Google even deeper reach into our personal data.

One thing is for certain: whether you're set to be an early adopter or you're still on the fence, this is only the beginning for smart homes.

Next big things

Welcome home! Check out some of the features of your oh-so-smart future abode...

Witt induction hobs

www.witt-ltd.com

Induction multizones sunk into the work surface automatically detect where a pan is placed; shut off when a pan is removed, overflows, or boils dry; and offer a pause function if you need to walk away suddenly.

Feed & Go Online Automatic pet feeder

www.feedandgo.com

All the scheduling and dispensing features of a traditional automatic feeder, plus a camera so you can share every gory detail of your pet gobbling up its dinner, and a voice recorder so you can leave it a secret mealtime message.

Lifx LED Bulb

lifx.co

Lets you set endless moods, selecting from over 16 million possible hues in a colour wheel on your smartphone. Can be programmed to brighten and dim slowly at opposite ends of the day, easing you out of and into sleep; to flash when you receive a text or email; and to come on automatically as soon as it detects your smartphone approaching your property. Highly energy efficient, it lasts 27 years.

Nest Protect

nest.com

Combined smoke/carbon monoxide detector gives you a heads up before sounding the full alarm, texts you when its batteries are low, alerts you of hazards detected while you're out and will shut down your Nest Thermostat if it sniffs something untoward.

Belkin WeMo Switch

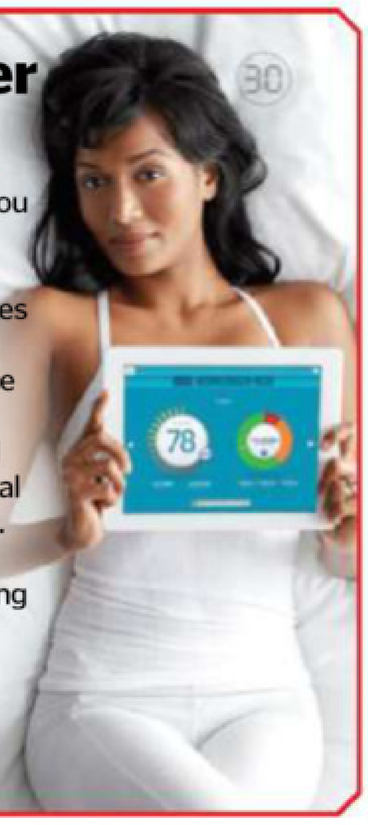
www.belkin.com

Lets you control any electric appliance remotely from your smartphone. Options to monitor how much energy your devices are consuming, or pair with a motion sensor so that, for example, walking through the front door turns on an appliance in another room.

Sleep Number Sleep IQ

www.sleepnumber.com

Sleep IQ monitors you as you sleep, tracking your heart rate, breathing rate, movements and sleep cycles to calculate the quality of your sleep and help you fine tune details like your bed time, mattress texture and daily habits to attain optimal sleep each and every night. Especially useful if your bedfellow is prone to snoring – Sleep IQ responds to the voice command "Stop snoring!" by gently raising your partner's head while they continue to slumber.



HomeChat by LG

lgusblog.com

With HomeChat you can converse naturally with your appliances to find out what they're up to and make requests. Your fridge might text you to remind you you're running low on milk; you can ask the washing machine, "where are you up to and when will you be done?" You can also set the robot vacuum to work an hour before you return home. They probably won't have any useful relationship advice for you, though.

PointGrab's PointSwitch

www.pointgrab.com

This nifty gadget allows you to control multiple appliances – lights, entertainment systems, air-con and more – from across the room simply by pointing and gesturing, so you won't even need to pick up your smartphone. PointSwitch uses motion-detection algorithms with a standard two-dimensional infrared camera to accurately identify your gesture and its direction. Just remember to turn it off before you start dancing on your own in the lounge...

Elertus Smart Sensor

www.elertus.com

Originally designed to monitor the temperature and humidity of cellars housing prize wines, the Elertus has ballooned into an all-encompassing watchdog that keeps tabs on anything precious to you. As well as clocking temperature and humidity, it will alert you if it detects movement, water, changes in light levels or doors opening and closing.

LED light transmissive carpet

www.philips.com

Carpet transmits light from programmable LED arrays laid underneath it. Use it to highlight the route to the bathroom in the night; guide inhabitants to safety during a fire; deliver instructions, directions or greetings to house guests; or – best of all – recreate the music video for *Billie Jean* right there in your living room. Maybe. No, definitely.

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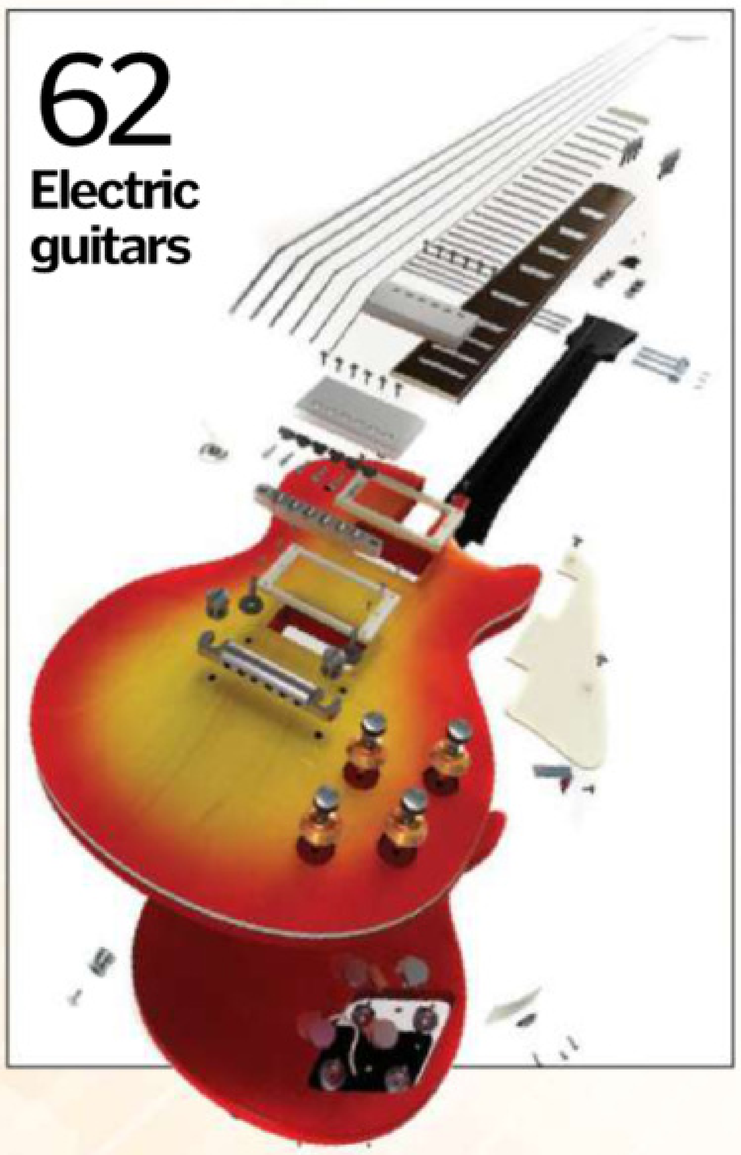

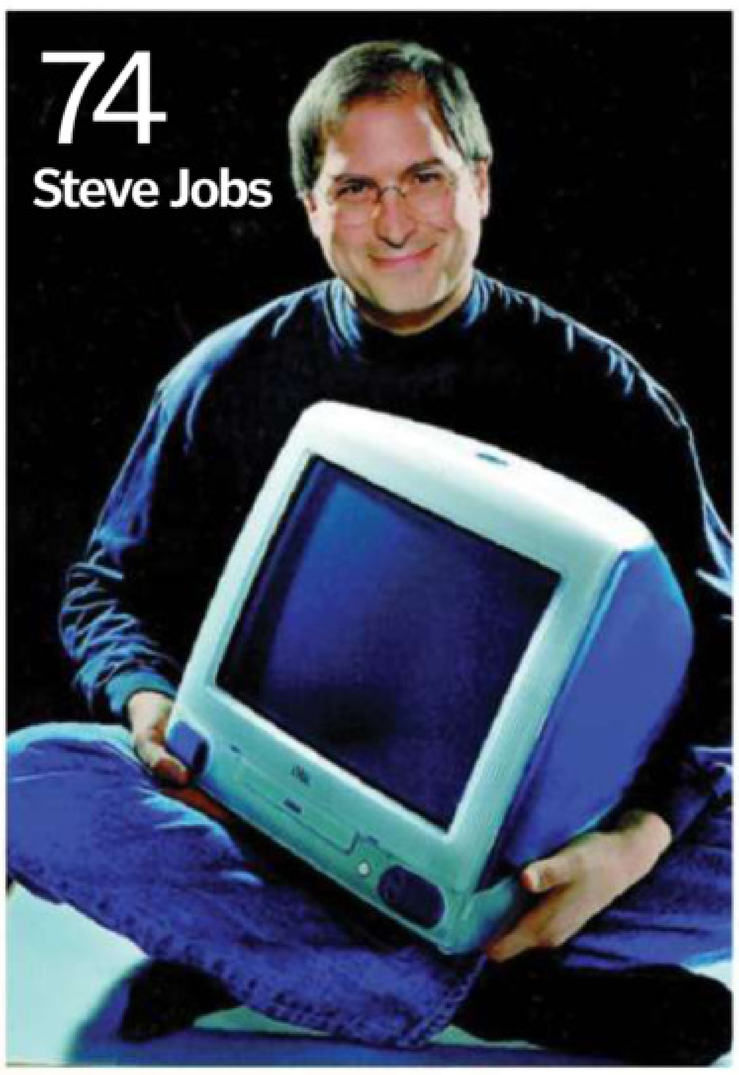

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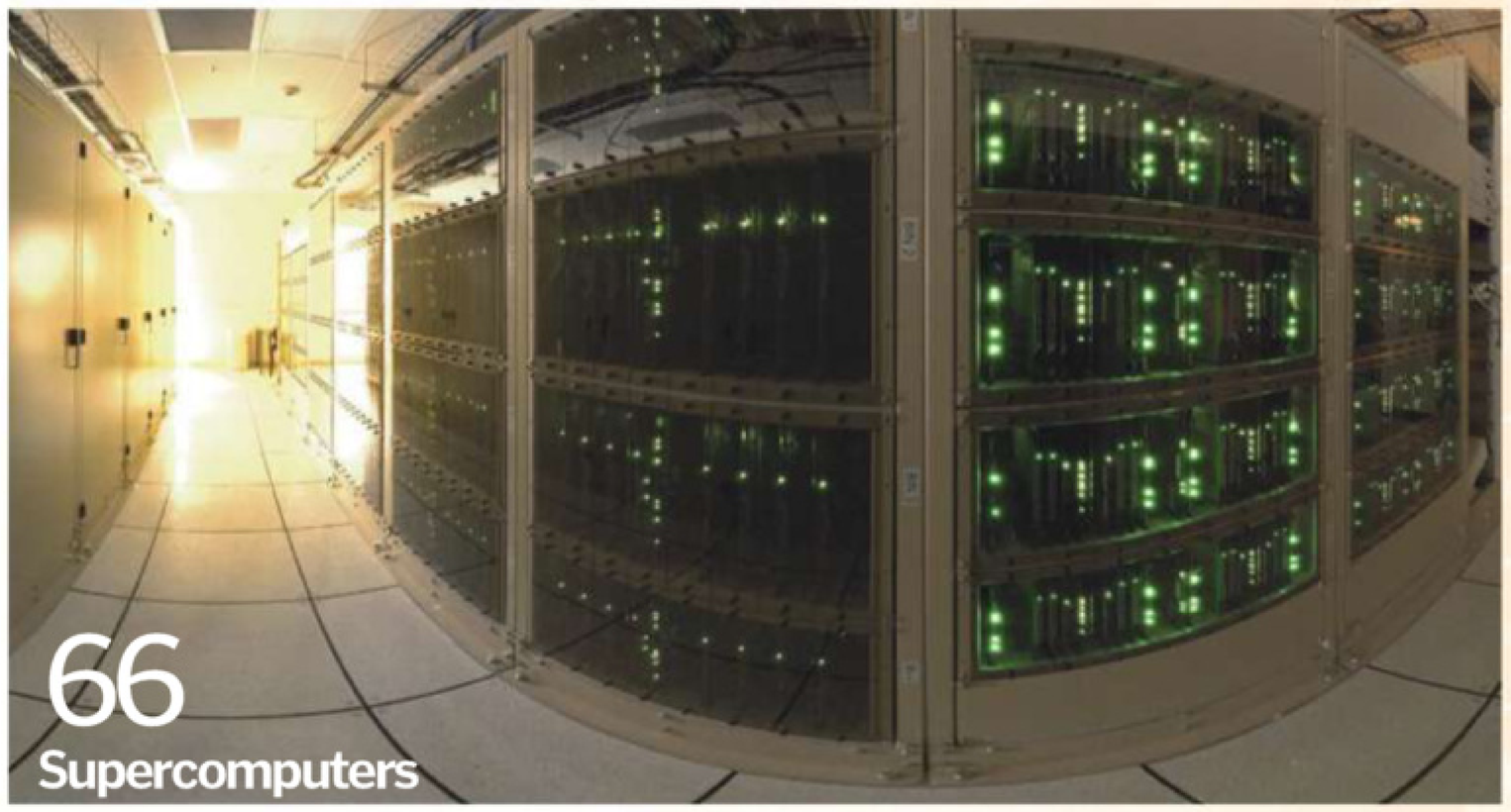
Waterproof smartphones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The ins and outs of why we might be taking virtual holidays in the near future

ARTIFICIAL INTELLIGENCE

THE GREATEST CHALLENGES WE FACE IN MAKING COMPUTERS THINK LIKE US

Intelligence is a tough concept to pin down. Is someone, or something, intelligent because they can multiply 29 x 18 in their head? What about emotional intelligence – working out if someone is sad, angry or faking an emotion? There's a fair few people who could solve the above sum (it's 522, if you were wondering) but wouldn't have a clue what to do when someone starts bawling their eyes out in front of them. All this makes the field of artificial intelligence a thorny path to tread.

British mathematician Alan Turing, most famous for his codebreaking work at Bletchley Park during World War II, got people thinking about computers as a tool for thought, rather than mere calculations. But where are we now in terms of creating computers and robots that can think, talk and perform tasks like humans? After recent advances in drone and interactive robot technology we are close to a breakthrough in AI, but have a little way to go yet before engineering a Samantha from *Her* or Skynet in *Terminator*.

Oxford University's professor of Computer Science, Nando de Freitas, has spent a lot of time studying the brain, trying to work out what goes on without us knowing it: "There's an area in the brain called the hippocampus, which is fascinating. In a rat, particular neurons will fire when it is travelling in a certain direction, but only for that direction. However, if it is in a different part of the room, a different neuron fires. That is how the rat knows where it is in the room. Each neuron is connected to the visual cortex,

5 TOP FACTS
AI LABS

1 CSAIL
The Computer Science and Artificial Intelligence Lab at MIT in Boston is one of the world's leading AI hubs, with 28 labs dedicated to artificial intelligence research alone.

2 Aldebaran
Commercial robot technology company Aldebaran is responsible for the creation of NAO, an advanced humanoid robot that can play games and interact with people.

3 Stanford AI Lab
Founded by AI pioneer John McCarthy in 1962, this lab at Stanford is dedicated to pushing technologies that will benefit humanity in its future progress.

4 Quantum AI Lab
A collaboration between Google and NASA, QuAIL focuses its research on developing a completely new kind of intelligence using quantum computers.

5 Facebook's AI Lab
NYU professor Yann LeCun is the director of Facebook's AI Lab, aimed at building on Deep Learning research to enhance understanding of its massive global user base.

DID YOU KNOW? *Despite of what Hollywood says, a robot revolution is unlikely as robots have no survival instinct of their own*

where we store images, and the auditory cortex, where we store sequences. Each neuron represents a location in the world and fires when you are there. Every time you excite a neuron in the hippocampus, it fires a certain set of neurons representing an image in the world, meaning, for example, you can now imagine your way home. Right now, we are trying to work out how to do that. We take intelligence for granted. You aren't aware of a lot of what's going on in your brain, which is why it's so hard to reverse engineer it."

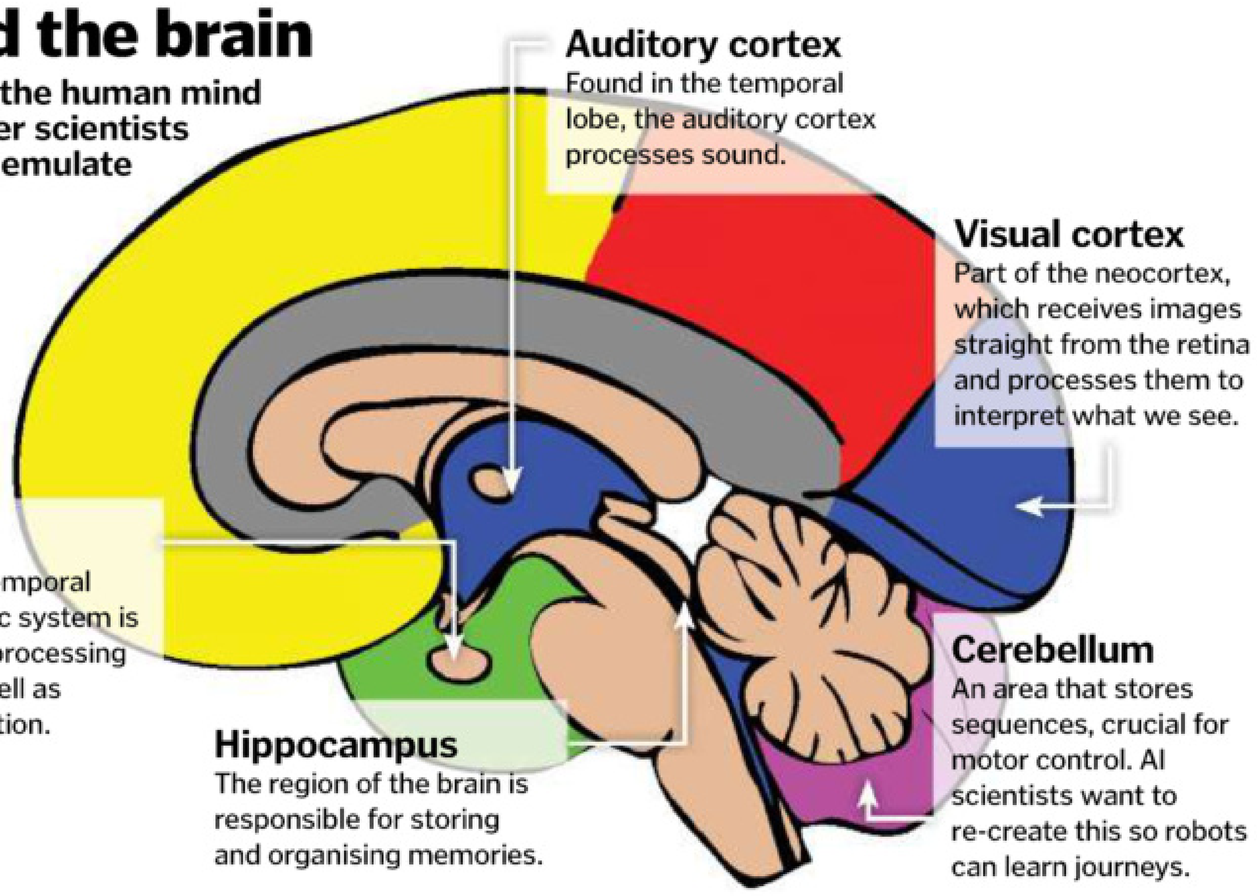
The argument that a robot is unable to be truly intelligent until it can feel emotions like a human is easy to refute. "Emotions are one of the easiest things to reproduce," argues De Freitas. "You don't need to build something as intelligent as a human to get an emotional response. If you were to poke the amygdala with a needle, you'll get an emotional response. That's because the amygdala is part of the old brain, which we share with rats, mice, cows, pigs and lots of other animals. The new brain – areas like the neocortex – is where we do our higher level of thinking."

So if scientists aren't looking at developing robots that get sniffly at *The Notebook*, how are they attempting to create the next generation of thinking robots? After all, we have had Deep Blue, the computer that defeated chess world champion Garry Kasparov in a duel, and Watson, the supercomputer that thrashed two champions in *Jeopardy!* What hurdles are they yet to overcome?

"I see intelligence as being able to interact with an environment and do the right thing," continues De Freitas. "Humans are able to plan their actions and engage in counterfactual reasoning, which is a fancy way of saying 'what if' reasoning. That is being able to perform an action and ask yourself: 'What would happen if I did

Around the brain

Key areas of the human mind that computer scientists are trying to emulate



Auditory cortex
Found in the temporal lobe, the auditory cortex processes sound.

Visual cortex
Part of the neocortex, which receives images straight from the retina and processes them to interpret what we see.

Amygdala
Found in the temporal lobe, this limbic system is involved with processing emotions as well as memory retention.

Hippocampus
The region of the brain is responsible for storing and organising memories.

Cerebellum
An area that stores sequences, crucial for motor control. AI scientists want to re-create this so robots can learn journeys.

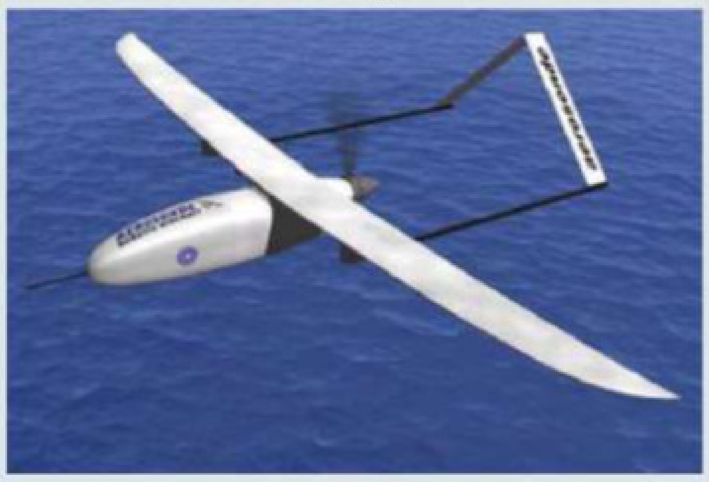
Despite struggling with some shorter clues, Watson easily beat its human rivals

Brain games

Deep Blue and Watson are amazing examples of supercomputers that were able to defeat the best human practitioners in chess and quiz show *Jeopardy!*, respectively. But what tech went into the duo? Deep Blue beat world chess champion Garry Kasparov in 1997, using its ability to assign values to the various pieces on the board and analyse 200 million moves per second using its AIX operating system and IBM SP Parallel System.

Watson came 14 years later and stunned the world by not only being able to understand the complex questions posed, but formulate a logical response from its stored database in seconds. In order for this incredibly powerful machine to work, Watson used 90 IBM Power 750 computers, which were the same as 2,800 high-speed computers, housing 15 trillion bytes of memory. Interestingly, IBM has recently announced a competition to push developers into incorporating Watson's intelligence into mobile apps.

AI tech today



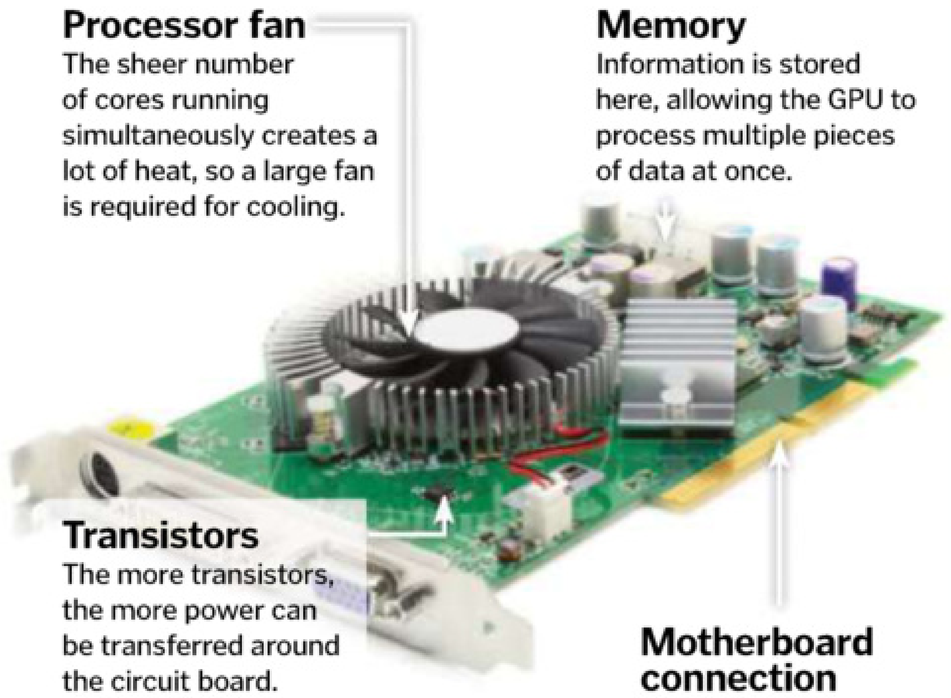
Drone aircraft
Unmanned aerial vehicles (UAVs) first emerged in the early-Fifties and can be used in warfare, reconnaissance, aerial mapping and scientific research. New technology allows UAVs to plot their own route without human intervention.

Phones & tablets
The most obvious bit of AI technology in your smartphone or tablet is in the camera. Facial recognition, allowing for easier focusing and tagging, is a real leap forward in intelligent image-capturing technology.

Advanced toy robots
Created by Aldebaran, NAO is an advanced humanoid robot. It can walk on a variety of surfaces, recognise images and faces, work out who is talking to it, and even play Noughts and Crosses (Tic-Tac-Toe).

Inside a GPU

One of the key ways that robots are able to catch up with humans in terms of raw processing power is by taking advantage of graphics processing units (GPUs). These computer chips are able to deal with more than one task at a time and cope with much bigger data sets than the central processing unit (CPU) that, until now, has been the standard command centre in robots and PCs. If you think of a computer like a rowing boat, the CPU is the cox (the brains of the outfit), while the GPU is the rowing force, providing the raw power to take the load off the cox. CPUs have a small number of cores, designed for sequential tasks, while GPUs have thousands of smaller cores so each can be put to work sifting through data at once.



Processor fan
The sheer number of cores running simultaneously creates a lot of heat, so a large fan is required for cooling.

Memory
Information is stored here, allowing the GPU to process multiple pieces of data at once.

Transistors
The more transistors, the more power can be transferred around the circuit board. Therefore, GPUs boast a lot more transistors than CPUs.

Motherboard connection
This is where the GPU is linked to the machine's mainframe.

AI in videogames

As many gaming devices now use GPUs as their processing chip, videogames are able to make use of the increased power and human-like thinking of NPC protagonists and antagonists. *Alien: Isolation* by Creative Assembly revisits the *Alien* film franchise and has you play as Ripley's daughter Amanda, trying to escape from the alien on board the Sevastopol space station. The alien doesn't run along a predetermined path, instead reacting to the player's behaviour. Not only that, but it learns whether you are a 'hider' or a 'runner'. The advanced game engine has the ability to make instantaneous decisions, thanks to a GPU that can make a lot of decisions at once, rather than rely on the CPU to make a series of linear decisions.

Also making the most of AI technology are fighting games like *Tekken 5: Dark Resurrection*. In the Yurin Dojo, you are able to battle a 'ghost character' in which you fight an opponent based on the combat style of another player. All the time you are playing the game, it gathers info about your fighting style in order to re-create you as one of the in-game characters!

AI tech in *Alien: Isolation* allows the enemy to adapt to your gameplay strategy

this other thing?' Robots are much smarter than us. They can perform logic and mathematical tasks much quicker. However, we can go from observing sequences in the world and build representations of them in our brains. This is what we are now trying to achieve with AI."

De Freitas is heavily involved with the development of Deep Learning, a programme which looks to replicate the human brain's ability to not only see an image but understand it as well – something major technology corporations like Google, Amazon and Facebook are keen to exploit.

"Deep Learning tries to get robots to build representations of the world and operate on those representations to build sequences in their mind. Then we want them to learn to construct different sequences. It's like if you take all the videos on YouTube, cut each video into ten-frame chunks and cut and paste them into new movies. The next step is to imagine alternative scenarios to what is put in front of them. We want computers to learn abstract representation about their environment and then think about their environment and the cause and effect of their actions.

"All the big search engines already use this tech. For Facebook, that means learning about users from all the data they input. You can learn a lot from the data that exists out there – even their IQ. They could use this data to start recruiting, or even become a life coach. No psychologist has ever had access to this amount of data. I talked to Mark Zuckerberg about this a few months ago. There's a reason why he's investing in this."

Google is also taking a close interest in the possibilities AI brings to the table. The company's reported £242 million ($400 million) acquisition of DeepMind, a London-based AI company, and their hiring of notable AI pioneers Ray Kurzweil and Geoffrey Hinton shows that the big players are keen to exploit this emerging technology.

The Google Chauffeur is a self-driving car, which is creating waves in Silicon Valley where executives are testing them out on public highways. Google reports that its cars have collectively driven over 800,000 kilometres (500,000 miles) without a single accident. There were 1,754 fatalities on Britain's roads in 2012 and more than 33,000 in the United States, while a further 145,000 were injured on US highways. De Freitas says that in the near future "cars will be way better than humans at driving." Computers are able to react much quicker than people. Google Chauffeur is able to make hundreds of diagnostic checks per second and only requires serious human intervention every 58,000 kilometres (36,000 miles) on average. Considering that in the UK in 2012, the average distance a person travelled in a year was around 10,800 kilometres (6,700 miles), you would need to drive for five years before having to take any action!

Another near-future application for AI is in the medical industry. Two robots that are already operating in Japan are the RIBA robot, which can lift patients comfortably and take instructions from an operator, and the Actroid-F, a human-like bot that can act as an observer to nurses. But, according to De Freitas, robotic nurses could very soon become a reality. "Robots can do diagnoses much faster than us. Right now, we send patients, including elderly people, home and the nurse only visits every now and again. If you instrumented their home, making sure it was non-invasive, you could train a system to detect when a patient is about to have a lapse so you could send an ambulance in time. It's not something that's enabled yet, but there are a few companies that are working on it."

So artificially intelligent robots are more than capable of performing complex tasks. But what happens when they fall into the wrong hands? "Just as people can use AI in cars to help us drive to work, people can also use AI to drive around and kill people. As someone who works on it and sees it coming, this is a very legitimate concern.

"We already have a lot of aircraft that fly autonomously. It's not a technology of the future. It's here now, so I think there should be a Geneva convention-type agreement to stop people misusing robots. But no, I don't see AI robots rising up and destroying us. If anything, I see them rising up to stop us killing each other.

"The AI robot of the future will be an intelligent machine of a different kind, like a rat is different from a human. They won't be human, because what makes us human is different from what makes a piece of silicon human."

KEY DATES

HISTORY OF AI

1642

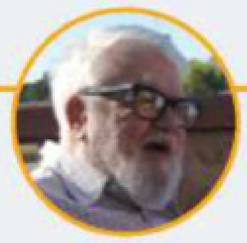
French mathematician Blaise Pascal invents a device that helps his taxman father add and subtract numbers.

1936

Alan Turing invents the Turing Machine – a theoretical computer that follows a set of directions.

1956

The first recorded use of the term 'artificial intelligence' is by John McCarthy, proposing a conference on the subject.



2011

IBM's Watson defeats humans in gameshow *Jeopardy!*, requiring unprecedented levels of speech recognition and hypotheses.

2012

Google executives begin testing self-driving cars on public highways.

DID YOU KNOW? *In 2012 a Brazilian researcher estimated that the average human brain has around 86 billion neurons*

Humans vs robots

Who comes out on top in the battle of the brains?

Planning ✓

This is where humans really trump computers. Humans can map out a series of sequences to lead us to a goal. Involving millions of neurons interacting in yet fully understood ways, computers lack this ability for now.

Logic ✓

Computers are extremely linear when it comes to thinking. Because of this – as well as their lack of emotional responses – they can work logically through commands to reach the best possible solution.

Speech recognition ✓

Computers are catching up, but humans still have the edge. Most humans can hear a sentence and extract meaning from it, based on experience and the situation. Few robots are able to do this, though natural language processing, like the iPhone's Siri technology, is constantly improving.

Maths ✓

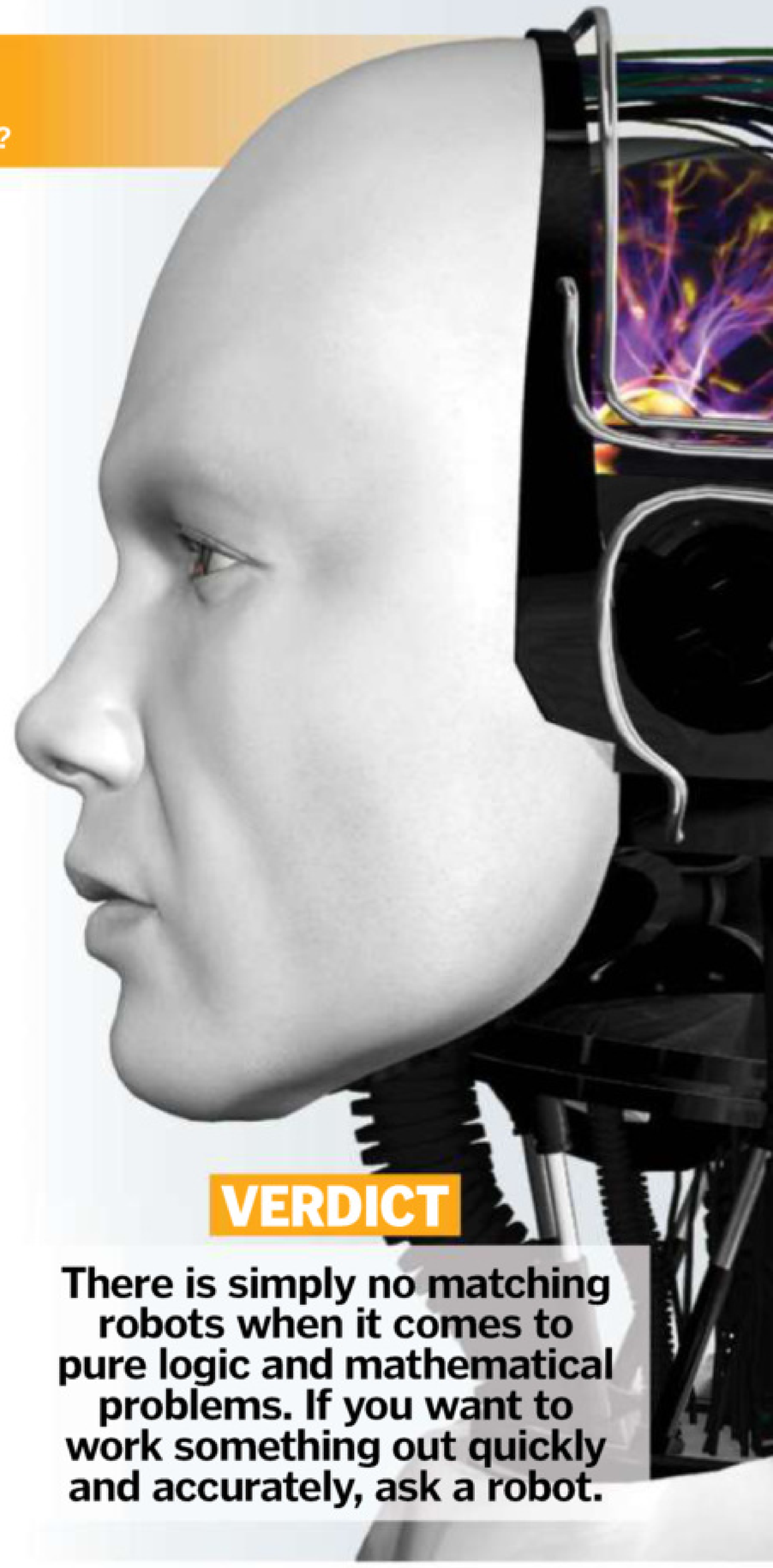
There's no denying it, computers are geniuses when it comes to doing sums. Just ask your calculator. Again, because base mathematics is the input of data and the extraction of a single solution, a simple programme can work through calculations extremely quickly.

Adapting ✓

Most computers are programmed in a certain way and are only able to react to what they have been taught. Humans have the ability to think creatively about a subject, due to our evolved neocortex, and come up with radical, outside-the-box solutions. Until roboticists are able to replicate the neural connections, we will stay ahead of robots when reacting to novel situations.

Speed ✓

Computers are able to operate at much faster speeds because they are stripped-down basic brains. Just think, even though a Land Rover may have more horsepower than a Ferrari, the latter is faster because it has less weight to hold it back. Similarly, when put to a task, a computer is able to work through a problem quicker, despite a human brain having more processing power.



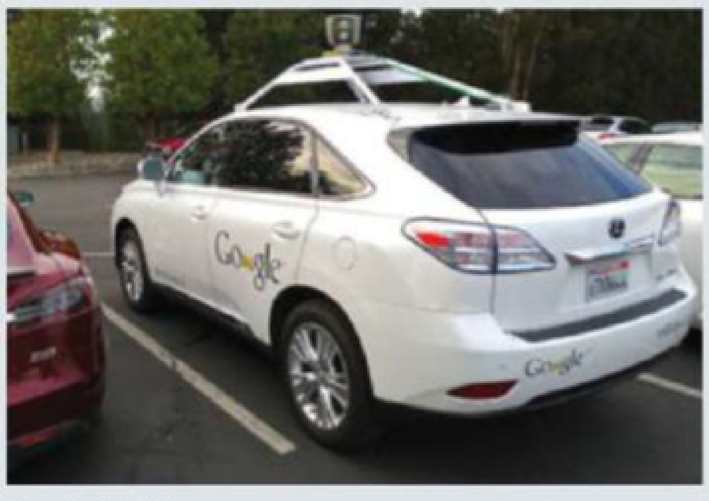
VERDICT

Humans still edge the battle of the mind on multilayered matters, such as forward planning, meaning that creative and on-the-spot thinking are still our forte.

VERDICT

There is simply no matching robots when it comes to pure logic and mathematical problems. If you want to work something out quickly and accurately, ask a robot.

Future AI tech



Self-driving cars

As yet only allowed to be driven in California and currently undergoing testing, this Google driverless car is an exciting pioneer that could herald a new era of transport, using advanced diagnostic tools to look out for hazards.

Robot medics

Machines could keep a watchful eye and run analysis on vulnerable patients faster and with greater accuracy. A trial is currently running at the Memorial Sloan-Kettering Cancer Center in New York, advising on lung cancer treatment.

Space vehicles

Work is progressing on space vehicles with 'human-like brains' that can plot their own route on treacherous planets like Mars by constantly analysing the terrain and making creative decisions, running off GPUs rather than CPUs.

© Alamy; SPL; Aldebaran Robotics; Thinkstock

Inside the OUYA

Meet the open-platform console which lets you play your videogames on a system that was designed to evolve

The OUYA is a videogame console that runs on a custom version of the Android 4.1 Jelly Bean operating system. Unlike many existing games consoles, however, the development of this machine was achieved through crowd-sourced funding, with the maker – OUYA, Inc – raising a whopping $8.5 million (£5.6 million) in 2012. Breaking from the norm, the OUYA has been designed as an open platform, with the device capable of being modified easily by owners.

As can be seen in greater detail in the teardown, the OUYA runs off an NVIDIA Tegra 3 system on a chip, which combines the console's CPU, GPU and memory. This, in partnership with a selection of mainboard ports and connectivity chips – including Wi-Fi and Bluetooth – allows the OUYA to be connected to a television or computer and run its own custom user interface (UI) off the Jelly Bean OS.

Key to the OUYA's UI is the OUYA store, which is the main conduit to the console's selection of games. Indeed, as the system has no physical media, all titles are installed on the console's storage drive (eight gigabits internal; expandable via USB or digital download). The majority of games currently available or confirmed are ports of titles already existing on the Android marketplace. Games are played via the OUYA's own Bluetooth-linked control pad.

The gaming side of things is combined with a host of media-related applications, including the open-source XBMC media player, TwitchTV live videogame stream broadcaster and iHeartRadio internet radio platform. Along with a selection of videogame emulators this completes the OUYA's stock package, but due to the system's open hardware and software architecture, many other applications and services are in the pipeline.

The next-gen gamer

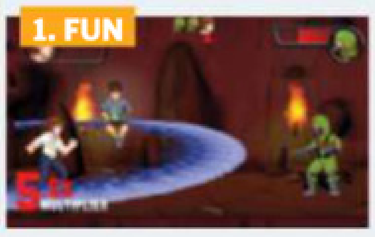
Take a look at the major components inside this cutting-edge gaming system

Fan
A Sunon MagLev DC brushless fan is fixed to the mainboard's heatsink. This is rated for 12V at 0.8W and cools the minimal hardware in the case.

Weights
Five small 11g (0.4oz) weights are screwed to the base of the case. These are for keeping the lightweight console upright when plugged in.

Casing
The OUYA's case is a 75 x 75 x 75mm (3 x 3 x 3in) plastic cube, with tapered corners at the bottom. The console's insides are accessed via a screwed-in panel located on the top.

Potentiometers
The controller's two analogue thumb sticks are tracked by potentiometers, which measure the sticks' degree of tilt in two axes.

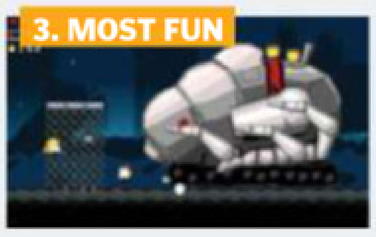


Saturday Morning RPG

An old-school RPG with an Eighties cartoon look, *Saturday Morning RPG* is an episodic title that was community funded too.

Final Fantasy III

The Nineties classic, remade in full 3D in 2006, gets a fantastic port on OUYA, with new story sequences and improved visuals across the board.



Gunslugs

A hectic 8-bit-style, side-scrolling shooter, *Gunslugs* is a pleasure to play and captures the Eighties arcade gaming scene with aplomb.

DID YOU KNOW? *The OUYA's development was funded by the public in just eight hours*

Ports

The OUYA has five ports: a DC-in power, microUSB, HDMI, Ethernet and USB 2.0. These feed the system power or are used to connect to the web, TVs and computers as needed.

System-on-a-chip

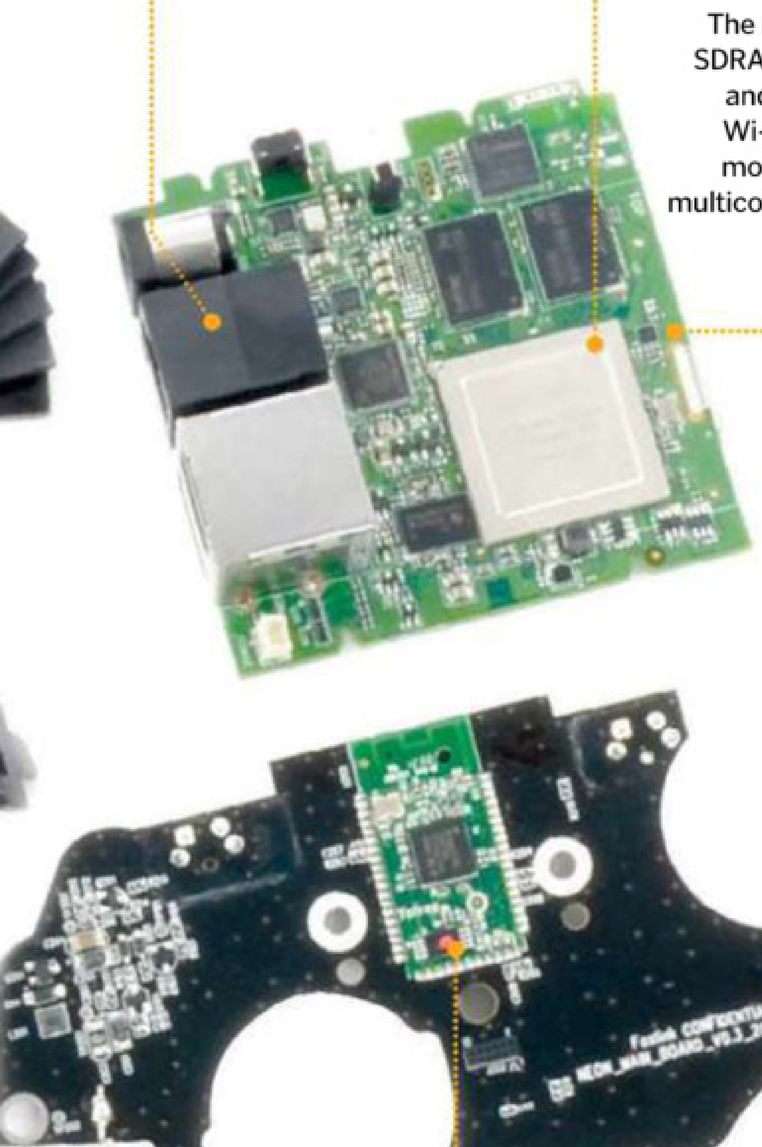
The OUYA's heart is an NVIDIA Tegra 3 system-on-a-chip (SOC). This primarily combines the CPU and GPU onto a single chipset, improving efficiency and also saving on space.

Heatsink

The system-on-a-chip is covered with a small heatsink. Soldered to the processor, this grants greater stability and some damage resistance should the device be dropped.

Mainboard

The mainboard holds the SDRAM modules, USB 2.0 and Ethernet controller, Wi-Fi and Bluetooth 4.0 module, NVIDIA Tegra 3 multicore CPU and Kingston 8GB flash memory.



Transceiver

A Broadcom Bluetooth 3.0 transceiver features an integrated ARM Cortex M3 processor. This receives all inputs from the controller and transmits them to the OUYA.

Touchpad

A 22.9 x 38.1mm (0.9 x 1.5in) touchpad is powered by a MA32P03 controller – this provides 2D mouse tracking for the OUYA system.

The statistics...

OUYA console

CPU: 1.7GHz quad-core ARM Cortex-A9

RAM: 1GB

Storage: 8GB internal flash memory

GPU: NVIDIA ULP GeForce

Dimensions: 75mm (3in) a side

OS: Android 4.1 Jelly Bean

Cost: Under $99 (£99)

© iFixit.com

Surround sound evolved

How does this modern speaker deliver spatial surround sound out of one box?

The SB60 airSOUND BASE from Orbitsound is a new breed of soundbar, an all-in-one speaker system that combines multiple loudspeakers, a subwoofer and a series of amplifiers and electrical systems into one thin box. What differentiates this unit from previous soundbars, though, is the inclusion of both a low-frequency speaker within its case – where traditionally soundbars have come with a separate subwoofer – and secondly, a unique airSOUND audio processing unit.

The airSOUND processor works by taking an audio recording's left and right electronic surround-sound signals, then separating and processing them into a 'main' and 'spatial' signal. The former is the recorded signal in its entirety, while the latter is the left and right signals with any common information filtered out. Common information includes any elements of the two signals that are identical, so in removing them each spatial signal only transmits the differences in the audio track, making for better sound quality and less distortion as caused by wave cancellation.

The included subwoofer – technically a low-frequency loudspeaker, as it produces audible frequencies too – is possible thanks to the vacuum-sealed, resin-bonded casing of the SB60. Indeed, the subwoofer and all four loudspeakers are located in their own sealed, irregularly shaped compartments to minimise acoustic reverberations and oscillations. The sub is placed in two compression zones that help it deliver bass frequencies without rattling in the box and surface it sits on.

Combined, the airSOUND spatial surround sound and integrated sub allow the SB60 to re-create an audio track's sound picture – the original position and timing of all the track's sounds – without requiring a number of traditional floor-standing speakers.

THE STATS
SB60 FIGURES

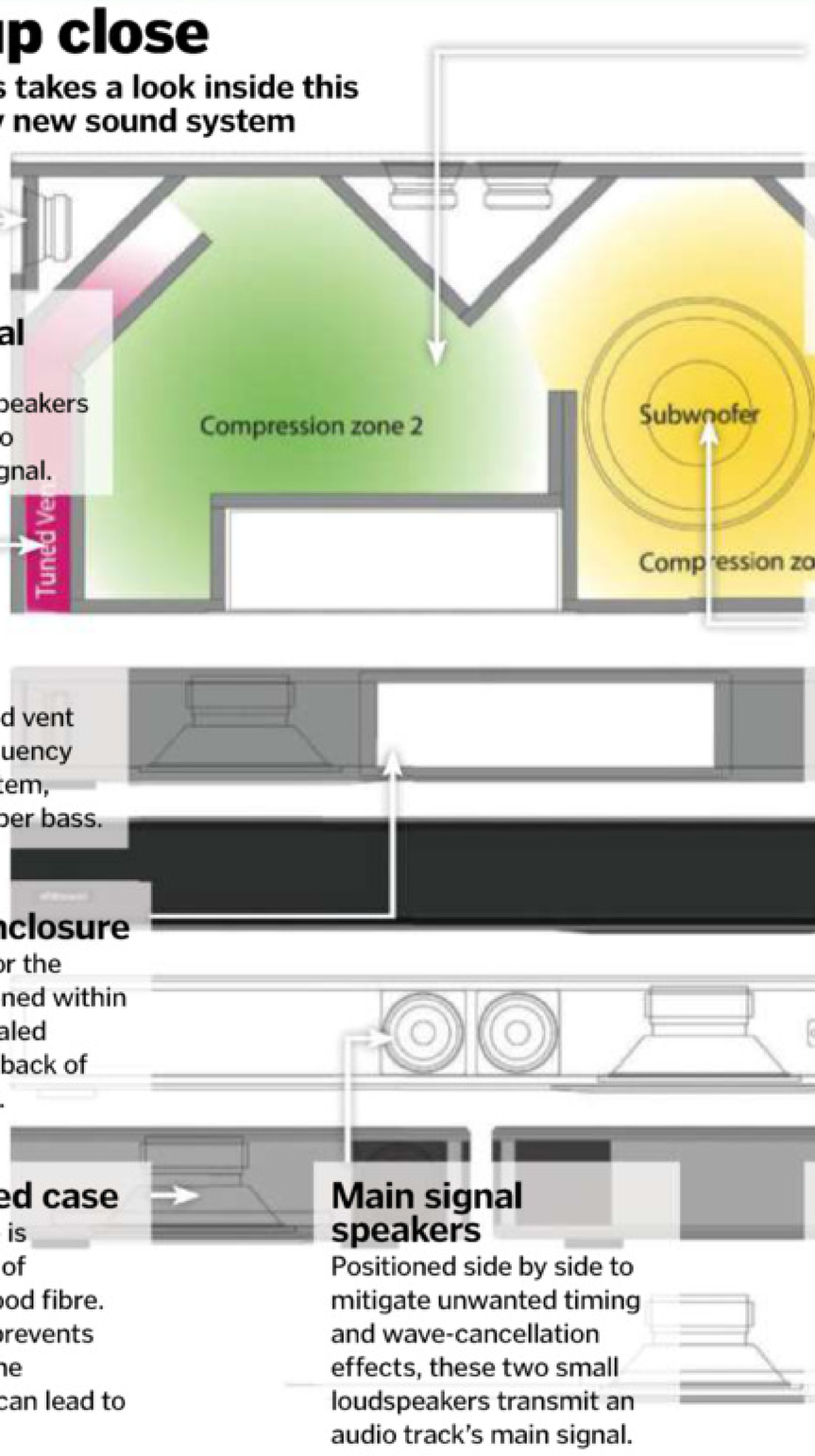
WIDTH 600mm | POWER OUTPUT 200w | CROSSOVER FREQUENCY 220Hz

MAX SOUND PRESSURE LEVEL (AT 1M) 95dB | HEIGHT 80mm | SPEAKERS 5

DID YOU KNOW? *The SB60 can be synced via Bluetooth to smartphones and tablets*

SB60 up close

How It Works takes a look inside this revolutionary new sound system



Compression zones
The compression zones within the SB60 ensure the low-frequency speaker (subwoofer) produces distortion-free base. This is assured due to their irregular shape and controlled air volume.

Spatial signal speakers
Two small loudspeakers transmit an audio track's spatial signal.

Subwoofer
The SB60's subwoofer is positioned within the vacuum-sealed compression zone one.

Tuned vent
The SB60's tuned vent extends the frequency range of the system, allowing for deeper bass.

Amplifier enclosure
The amplifiers for the SB60 are positioned within a rectangular sealed enclosure in the back of the unit's casing.

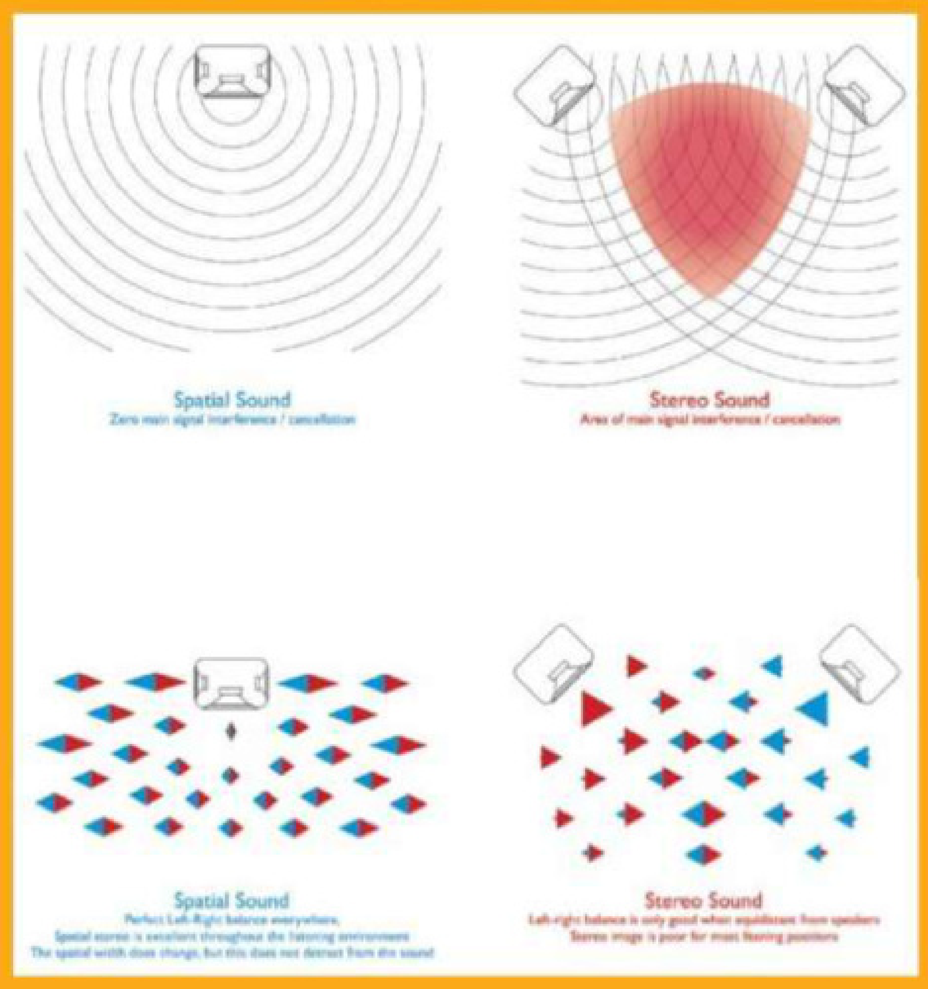
Resin-bonded case
The SB60's case is constructed out of resin-bonded wood fibre. The sealed box prevents leaks between the enclosures that can lead to audio defects.

Main signal speakers
Positioned side by side to mitigate unwanted timing and wave-cancellation effects, these two small loudspeakers transmit an audio track's main signal.

Ports
In terms of connections, the SB60 has a S/PDIF Optical port and two 3.5mm (0.14in) minijack stero inputs.

Spatial vs stereo sound

Because of the way the audio signal is treated in the SB60's airSOUND processor, the left-right input of an audio track is converted to a main and a spatial signal: the main signal being everything in the whole recording, while the spatial signal is just the bits that tell a user's ears/brain where things are (ie the sound's direction). Now, as when two stereo speakers reproduce a sound source they are merely playing the main signal from two separate sources, there are timing errors and areas of distortion, both of which lead to a poor audio experience. By splitting off these directional cues and transmitting them through the side speakers, the spatial quality of the original recording is maintained to a far higher degree, so a more natural sound is generated.



Man behind the SB60

We speak to the SB60 designer, Ted Fletcher, to find out what technology makes this soundbar so special

Tell us about the development of the SB60.
Recently there has been a shift in the industry where people have begun to say, "Why do we need a subwoofer in a sound system? It's large and takes up space in the corner of a room, and we don't like it." So the technical guys and I started to think if there was a way that we could incorporate bass frequencies into a small unit. We ended up deciding to stand the television on top of a very thin large speaker box and incorporate everything into it. We then built 20 prototypes perfecting the system – the result was the SB60.

So, how does the SB60 work?
The basis for the technology is that you have a main signal and a spatial signal. What we have done with the SB60 is that the main signal is generated by two small 45-millimetre (1.8-inch) loudspeakers positioned side by side at the front of the SB60. These speakers are in their own enclosure, which is triangular so the acoustic reflections inside the enclosure don't bounce backwards and forwards off parallel surfaces. This improves audio performance massively.

The spatial signals, which are responsible for telling your ear where things are, are generated by two small loudspeakers positioned on the sides of the unit. Again, these speakers have their own triangular enclosures to minimise the negative effects of acoustic oscillations.

The whole thing is constructed out of resin-bonded wood fibre and is super high-density. The box is bonded together to prevent leaks between the enclosures. This is necessary, as each compartment needs to be acoustically separated to be effective. That is why the SB60 is vacuum-sealed, because if you have any leaks at all you get unwanted hissing noises from the high pressure built up within the loudspeakers.

Now we come to the interesting bit: the bass frequencies. We don't technically have a subwoofer in the SB60; it is more of as low-frequency speaker, as the frequency that it crosses over at is around 200 Hertz, so it does audible frequencies too. Anyway, that is mounted very rigidly inside the box, and behind it you have a large compression zone, which is split into two. The reason why the compression zone is split is because the second zone's irregular shape does a very good job in loading the back of the speaker without there being any nasty oscillations. Finally, there is a tuned vent at the back of the compression zones, which helps make the frequency range even lower.

Why is the SB60 better than any other soundbar available?
All other soundbars produce sound from their loudspeakers that is very similar. The speakers are also all separated in space by more than a couple of feet. With those setups you get interaction between the loudspeakers, wave cancellation effects in the air and distortions.

© Orbitsound

Building wax figures

Discover how lifelike models are made step by step

Wax figures have been around since the Middle Ages and are made from a combination of beeswax and Japan wax. To construct a wax figure, first a clay model is made – this model is used to generate a mould. The wax mixture melts at low temperatures and a layer of molten wax is poured into the mould. Once set, the wax remains soft enough to be carved, but durable enough to create a lasting, detailed statue. Heated metal tools can be used to chase away any seams or imperfections in the surface, and to melt sockets in the face for the eyes and teeth. The softness of the set wax also allows individual hairs to be embedded – one of the most time-consuming parts of the process. Finally, layers of oil-based paint are used to create realistic skin colour and texture.

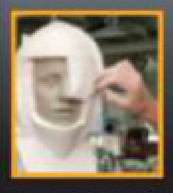
A spotlight on Madame Tussaud

Marie Tussaud was a French sculptor, born in 1761. Her mother worked as a housekeeper for wax sculptor Dr Philippe Curtius, and under his tuition, Tussaud learnt the craft. During the French Revolution, Tussaud made death masks of some of the most infamous victims of the guillotine. Tussaud then travelled to England, and in 1835, she opened her first permanent exhibition on Baker Street in London. It originally had 400 figures, including a popular Chamber of Horrors exhibit still loved today. After Tussaud's death in 1850, her grandson, Joseph Randall, commissioned the move to Marylebone Road.

Wax sculptors spend months creating their super-lifelike models

1. Clay model

To capture a true likeness, wax sculptors use a combination of photographs, video footage and body measurements. First a steel and aluminium skeleton is constructed and a rough outline of the musculature is created using chicken wire and newspaper. The body is then positioned, before being covered in clay and sculpted.

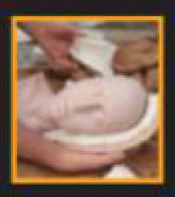


2. Make a mould

Moulds for wax figures are made from different materials. For the head, a plaster mould is often used. For the body, steel supports and hessian sacking are added to the plaster to support the additional weight of the mould. For hands, meanwhile, the moulds can be made of dental alginate.

3. Cast the wax

The plaster mould for the head is filled with molten wax. Wax contracts as it solidifies, so the clay sculptures and resulting moulds are made two per cent larger than the size required. For the hands, a flexible plastic known as 'elvex' is sometimes added to the wax to prevent the digits snapping. The body is cast in resin and fibreglass.

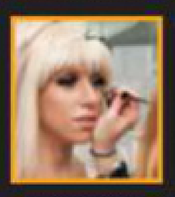


4. Add the hair

After the wax figure is removed from the mould, any seams are melted away, and further detail is carefully added to the face and hands. Each individual hair is hand poked into the wax figure's head using a fine fork-ended needle; this stage can take up to six weeks to complete.

5. Eyes

Next up is a feature that really transforms the model from inanimate mannequin to realistic human double: the eyes. The glass eyes are carefully painted with watercolours, using silk thread to build up the patterning on the iris. Teeth are constructed using dental acrylic, with a silicone mould taken from the subject's mouth.



6. Paint the skin

Like skin, wax is translucent, providing the perfect base. Skin colour is built up using oil-based paint. The paint is stippled onto the wax to create a realistic texture. The artists take into account the pose of the statue, as well as the display lighting, to create realistic shadows across the figure.

© The images shown depict a wax figure created and owned by Madame Tussauds

THE STATS
XPERIA Z ULTRA

DIMENSIONS 179x92x6.5mm CPU 2.2GHz quad-core
WEIGHT **212g** DISPLAY 1,920x1,080px BATTERY **3,000mAh**

DID YOU KNOW? *The first commercial waterproof mobile phone was the LG CanU 502S released in 2005*

Waterproof smartphones

How do these electronic devices carry on working even when underwater?

Today there are two main methods for waterproofing a smartphone: physical barriers such as port covers and sealed seams that prevent liquid entering externally, and nanocoatings that penetrate the device entirely and actively repel water. While both techniques are used, the most effective is the latter, enabling devices to be water resistant without compromising on size and aesthetics.

There are different types of nanocoating, but one of the most commonly used is that made by P2i. This company's waterproofing process involves subjecting any electronic gizmo to a plasma-enhanced vapour in a vacuum chamber at room temperature. The vapour contains a gaseous polymer, which when brought into contact with the device's surfaces – both external and internal – forms a super-strong covalent bond and waterproof barrier 1,000 times thinner than a human hair.

Once on the phone, the ultra-thin polymer layer then dramatically reduces its surface energy, forcing any water that comes into contact with it to bead up and be repelled.

Simply put, the coating acts in a similar way to the waxy feathers on a duck's back, preventing water from infiltrating the top layer and forcing it to run off the sides. Obviously, in the case of a smartphone, this action would prevent water from penetrating the delicate internal components. However, due to the vapour disposition process, even if water were to penetrate the mobile's casing, each internal component would also be coated with the polymer, protecting them until the water evaporated or was dried off manually.

A phone worth splashing out on

We pick out the key components that keep the Xperia Z Ultra super-dry

Port covers
Each port on the Z Ultra comes with a protective cover. These prevent water entering while submerged.

Tough materials
Thanks to a hardened glass front and back covers, plus encircling metal frame, the phone can remain underwater for up to 30 minutes.

Depth
As the Z Ultra is IP55/IP58 certified, it can be submerged in up to 1.5m (4.9ft) of freshwater without risk of damage. It is also protected from low-powered jets of water.

Waterproof phone rivals

1 Motorola Defy
With a single-core 800MHz CPU, 512MB of RAM, a 1,540mAh battery and a small 9.4-centimetre (3.7-inch) screen, the Defy is very much an entry-level water-resistant phone.

2 Samsung Galaxy S4 Active
With a quad-core 1.9GHz Snapdragon CPU, 2GB of RAM and Android 4.2.2 installed, the S4 Active is a decent-spec, good all-round smartphone that can take the plunge.

3 Sony Xperia Z Ultra
With a huge 16.3-centimetre (6.4-inch) screen, 2.2GHz quad-core CPU and 8MP camera, the Z Ultra is by far the largest and highest-spec waterproof phone on the market to date.

© Sony; Samsung; Robot8A

Electric guitars

What technology lends these iconic instruments their distinctive sound?

The electric guitar is probably the defining sound of 20th-century music. Like all good inventions, it solved a problem: in a band with several instruments, guitars were too quiet. In the Thirties, several guitar manufacturers developed the magnetic pick-up, which fitted underneath strings and fed an electric signal to an amplifier.

Modern guitars work in exactly the same way. Strings are made from ferromagnetic metal, usually nickel or steel. The pick-up is a bar magnet housed inside thousands of turns of wire. The vibrating strings cause fluctuations in the magnet's field, which in turn induces an alternating current in the wire. This current is the signal which is carried to the amp. Electric guitars can have a single pick-up for all the strings or one for each string.

Guitars could be heard, but the audience heard something else too: horrible howling feedback. The hollow body of the first electric guitars vibrated with sound waves from the amp, so this second problem was solved by introducing a solid body.

There is a fierce ongoing debate around who created the first solid electric guitar, but the most popular and widely sold early model was the Fender 'Broadcaster' (later called 'Telecaster'), followed in 1954 by the company's legendary 'Stratocaster'.

Manufacturers have tried making plastic, aluminium, twin-necked and headless guitars – even 'synth' guitars with MIDI (musical instrument digital interface) technology. But for the most part guitarists prefer the original; they might dabble for a while, but they always go back to the traditional six-string design.

While amps, MIDI and USB systems have all improved, providing better ways to record and enhance music, the electric guitar itself is fundamentally the same as it was in the Fifties – a testament to its well-conceived design.

Acoustic vs electric

All guitars have a body, neck and strings. Electric guitars need ferromagnetic metal strings while acoustic guitars can use strings made from nylon, bronze, brass or metal-wrapped nylon. Both acoustic and electric guitars are usually made of wood. Wood is ideal because it's relatively cheap, light and easy to shape – not to mention the fact that it also lends guitars their distinctive warm sound.

The main difference between the two types of guitar is how they produce sound. The hollow body of an acoustic guitar provides a big chamber for air to reverberate. Pluck a string and the vibration travels through the bridge into the body. The body and air inside it vibrate, creating compressed sound waves. For an electric guitar, you need an amp (or computer) to produce sound worthy of being called 'music'.

Amp up the volume

Amps boost the input signal from the guitar and drive the speaker cone. Plugged in, the weak fluctuating signal from the pick-ups passes through a series of transistors, modifying the amp's DC circuit. Next the vibrating cone generates sound waves, replicating and amplifying the sound produced by the strings.

When vacuum tube amps were replaced by solid-state amps in the Seventies, guitarists complained they sounded 'colder'. Modern amps often combine the two types for a warm but loud sound, and if your computer has a fast enough processor, you can use it as a virtual amp.

907kg

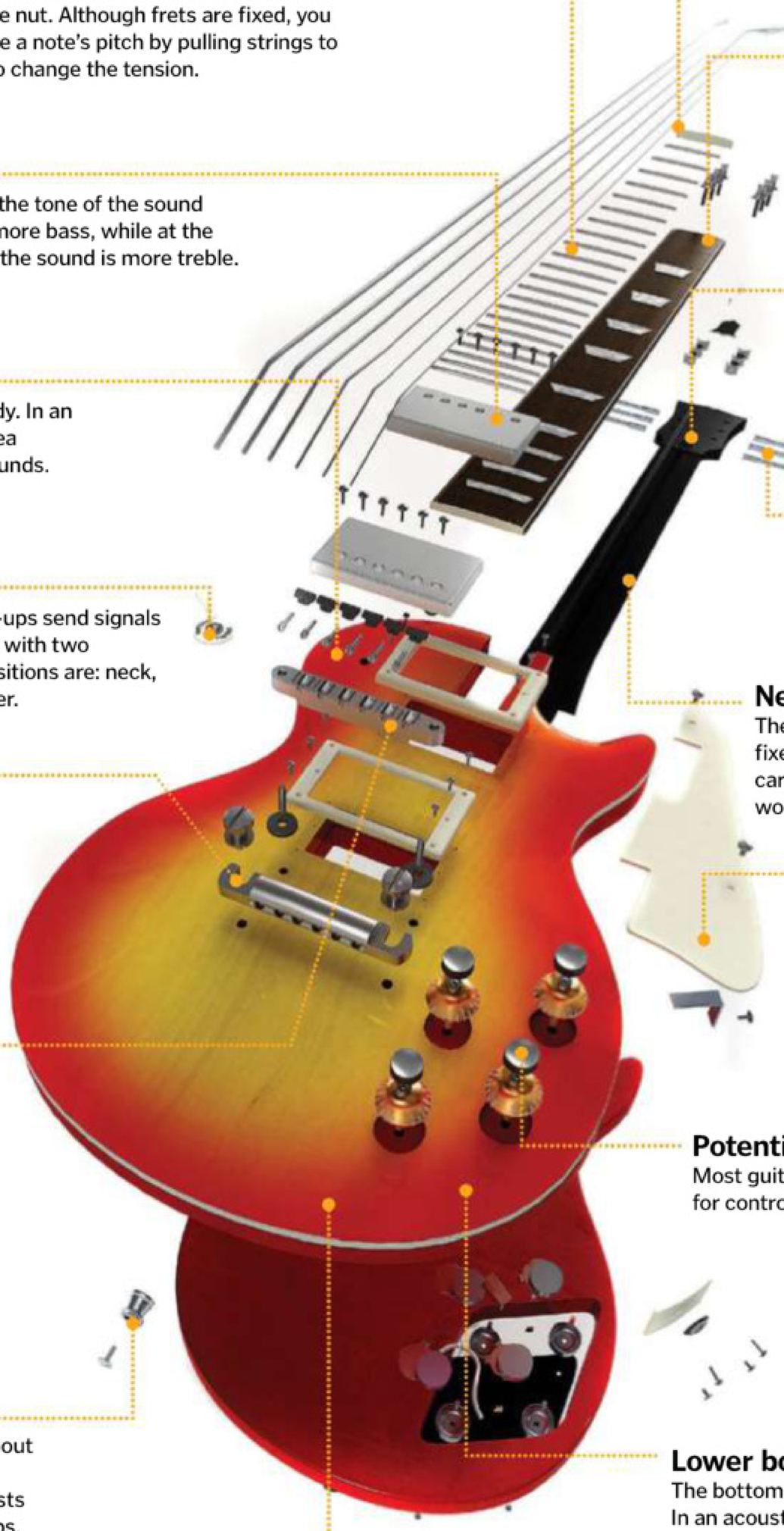
LARGEST PLAYABLE ELECTRIC GUITAR

School students in Conroe, Texas, made a 12:1 scale version of a 1967 Gibson Flying V. It stands 13.3m (43.6ft) tall, 5m (16.4ft) wide and weighs 907kg (2,000lb). It was first played in public in June 2000.

DID YOU KNOW? *Amazingly, Leo Fender – manufacturer of the famous 'Stratocaster' – couldn't play guitar*

Teardown of an electric guitar

What are the major components of these amazing instruments?



Fret
The thin, raised metal bars across the fingerboard. The distance between frets corresponds to one semitone (12 semitones make up one octave). The first fret is the one nearest the nut. Although frets are fixed, you can change a note's pitch by pulling strings to one side to change the tension.

Pick-ups
Nearest the neck, the tone of the sound picked up here is more bass, while at the bridge the tone of the sound is more treble.

Upper bout
The top area of the body. In an acoustic guitar, this area produces the treble sounds.

Pick-up selector
This selects which pick-ups send signals to the amp. For a guitar with two pick-ups, the switch positions are: neck, bridge and both together.

Saddle tailpiece
This can be adjusted to change string length and therefore tone.

Bridge
Holds the strings away from the body. The strings may terminate here or just pass over it. The height of the bridge can also be modified with screws.

Strap button
One on the upper bout and one under the body. Many guitarists prefer locking straps, which prevent them from coming adrift mid-performance.

Body
Usually kiln-dried hardwood (mahogany, ash, walnut, etc), the heavy body prevents unwanted vibrations.

Lower bout
The bottom area of the body. In an acoustic guitar, this part produces the bass sounds.

Potentiometers
Most guitars have at least two pots for controlling volume and tone.

Nut
This holds the strings in their right places and feeds them into the tuning pegs. You can lubricate the grooves in the nuts with graphite from a few swipes with a pencil.

Fingerboard
A player can press down on the strings here to change the vibrating length and therefore the pitch of the note.

Headstock
This holds the strings and can be flat or angled. The shapes are unique to each model.

Tuning pegs
Also called machine heads, these can be twisted to adjust the tension on the string, changing the pitch of the note it produces.

Neck
The neck can be adjustable or fixed, or 'straight-through' – carved from the same piece of wood as the body.

Scratchplate
This protects the finish of the body from plectrum and nail scratches. It's usually made of plastic but can be glass, wood or even fabric.

Jargon buster

Pick-up
A bar magnet wrapped in a coil of wire. Vibrations in the strings cause vibrations in the magnetic field, which induces a current in the wire.

Headstock
Aka a 'peg-head', this holds the strings under tension.

Cutaway
This indentation in the body near the neck allows the player easier access to the upper frets. There are two types: the rounded Venetian and more pointy Florentine.

Wah-wah pedal
This pedal controls the bass and treble. It's pushed down to emphasise treble and left up for bass. To get the 'wah-wah' sound, you just have to rock it up and down.

Potentiometer
A variable resistor used to adjust volume or tone. Knobs on guitars and amps are commonly called 'pots'.

Passive/active
Most electric guitars don't require electric power (only the amp) so are 'passive'. Some, however, do use power (from a battery or USB) to create effects, so are 'active'.

Licks/riffs
Licks are short musical phrases played in a solo. Riffs are short melody phrases which are repeated.

Learn more

If you've recently started playing the guitar, **Guitar for Beginners** is full of tips and tutorials. Check it out at **bit.ly/1iOVqQ8**.

© DK Images

How mobile calls work

The tech behind making phone calls

Our mobiles are portable gaming consoles, computers, alarm clocks and personal assistants all in one, but they're still pretty useful for calling someone without being tethered by a cord.

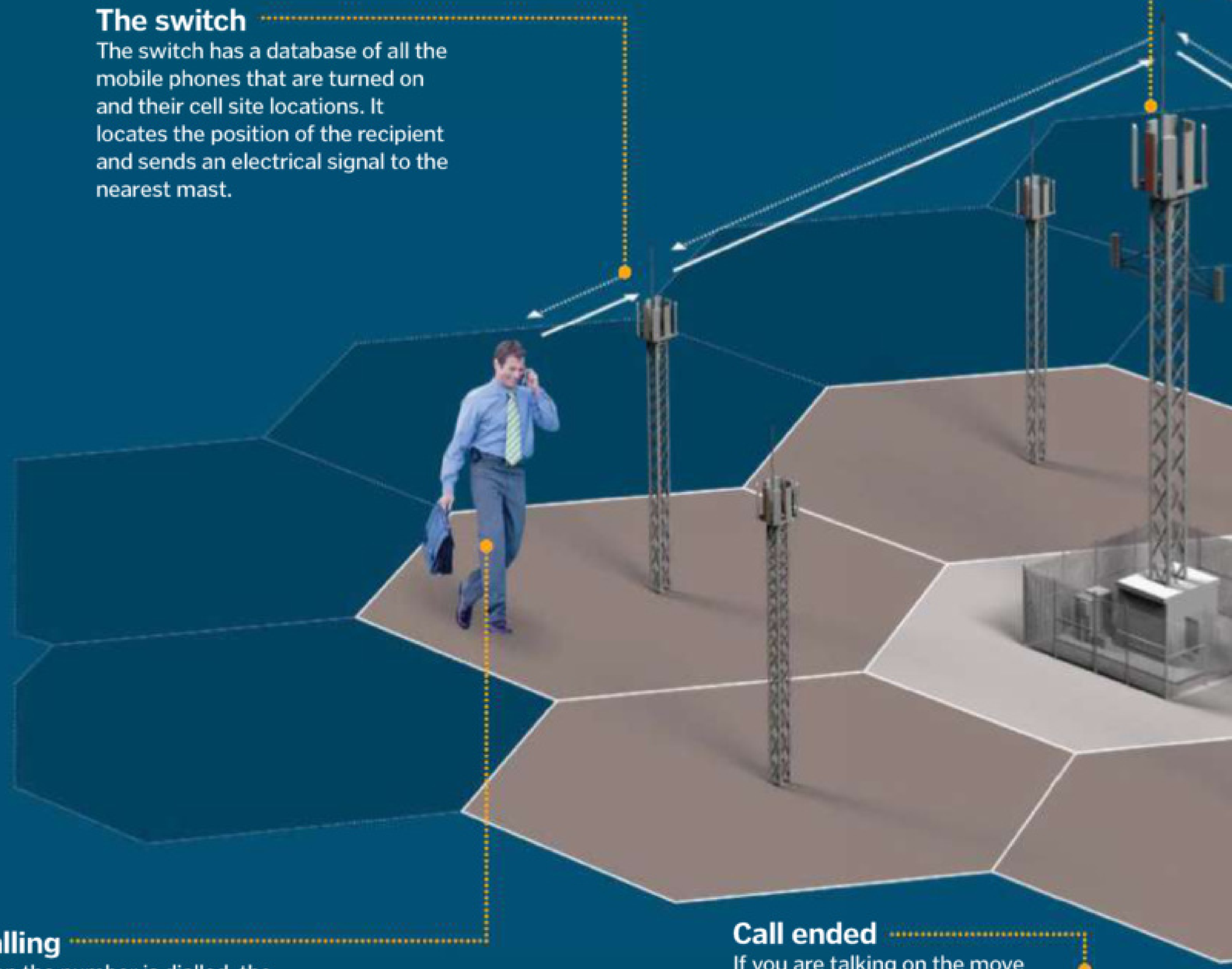
Unlike land lines, mobile phones work by sending electric signals via radio waves to mobile phone towers or masts. These masts pick up the signal, transmitting it along a network of masts until they reach the closest one to the phone receiving the call. Once there, the radio waves are finally beamed to the target phone and converted back into electronic signals and then into sound waves that enter the recipient's ear.

Mobile phone masts are placed several kilometres apart in rural areas but can be just a few hundred metres from each other in cities. There will be one mast per 'cell', which is the maximum area in which the mast can pick up a mobile signal. Hence the further away you are from a mast, the weaker the signal, so if you cannot get a signal at all, that means you aren't within range of a mast. As well as the large main masts, there are also a number of micro and picocells that are much smaller and have less coverage. However, these can pick up the radio waves and transmit them to the larger main masts, increasing the coverage without being an eyesore.

This network allows people to call wherever and whenever they want, only having to be within range of a tower. Even though satellites are required for long-distance calls that can't be transmitted from tower to tower, the process of making a phone call by relay is an amazing technological victory.

Sending mixed signals

How your calls get from A to B while on the move



Roaming
Roaming charges are made when a user heads out of their service provider's reach and uses another's mast instead.

The switch
The switch has a database of all the mobile phones that are turned on and their cell site locations. It locates the position of the recipient and sends an electrical signal to the nearest mast.

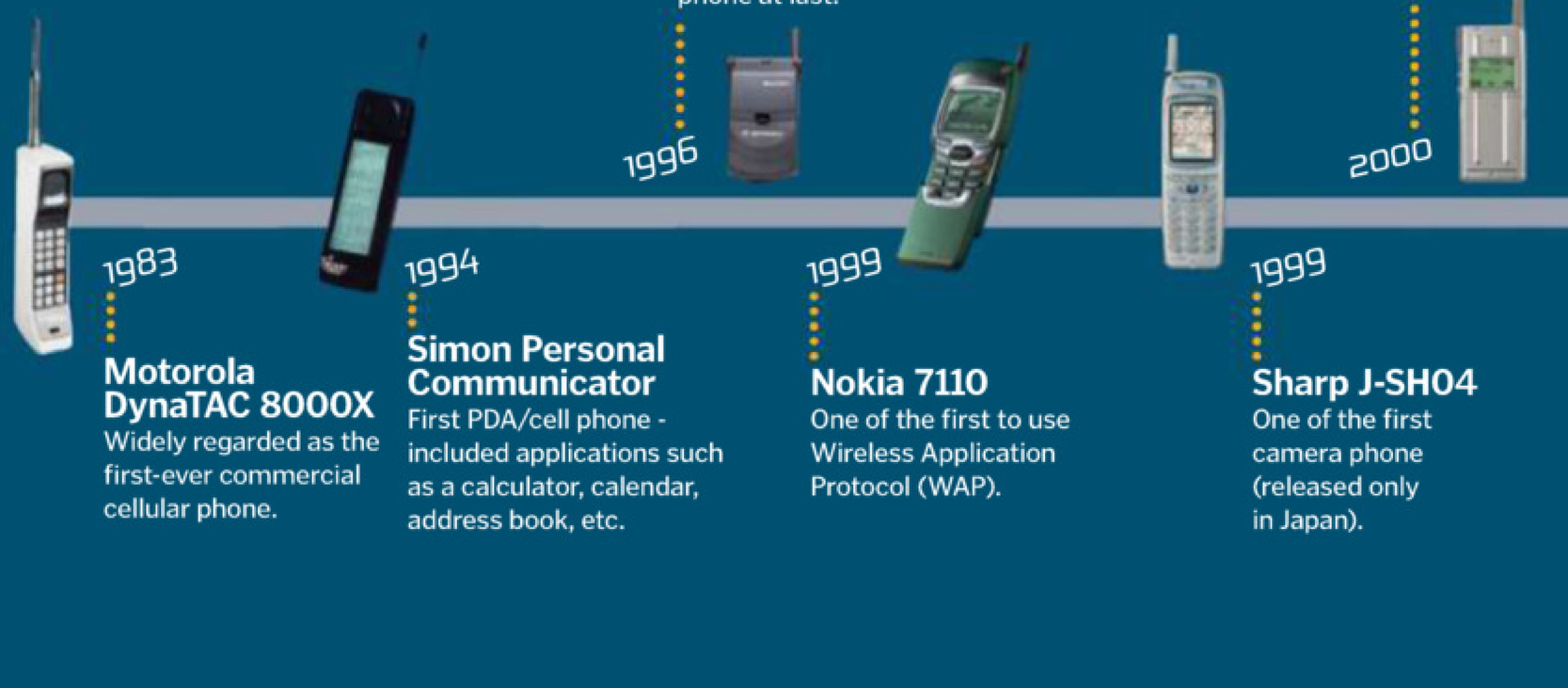
Dialling
When the number is dialled, the antenna at the local cell site identifies the caller and the recipient. A cell site is where antennas and communications equipment are placed inside a mast or tower.

Call ended
If you are talking on the move and travel out of range of a phone mast, the phone call will cut off.

First smartphones

Most of you reading this will have a smartphone in your pocket or within arm's reach. The world's first smartphone is generally considered to be IBM's Simon Personal Communicator from the 1990s. It surpassed any other mobile at the time, as it sent and received emails, had a calculator, calendar, games and even a touchscreen, which was a revolutionary concept back then. It even had a basic predictive text function.

But it was not a commercial success, so the first smartphone to really take off was the Kyocera 6035, launched in 2001. It had an attached modem that wirelessly to the internet to send and receive emails and had 8GB of memory. It made work on the go a real possibility without the need for cables or heavy laptops.



1983 – Motorola DynaTAC 8000X
Widely regarded as the first-ever commercial cellular phone.

1994 – Simon Personal Communicator
First PDA/cell phone - included applications such as a calculator, calendar, address book, etc.

1996 – Motorola StarTAC
First clamshell cell phone – design reaches the cell phone at last.

1999 – Nokia 7110
One of the first to use Wireless Application Protocol (WAP).

1999 – Sharp J-SH04
One of the first camera phone (released only in Japan).

2000 – Samsung SPH-M2100
The first MP3 cell phone.

5 TOP FACTS
MOBILE DATA

Heavy lifting
1 The first-ever commercial mobile phone was the Motorola DynaTAC 8000X, which weighed 790g (28oz), or about the same as seven modern smartphones.

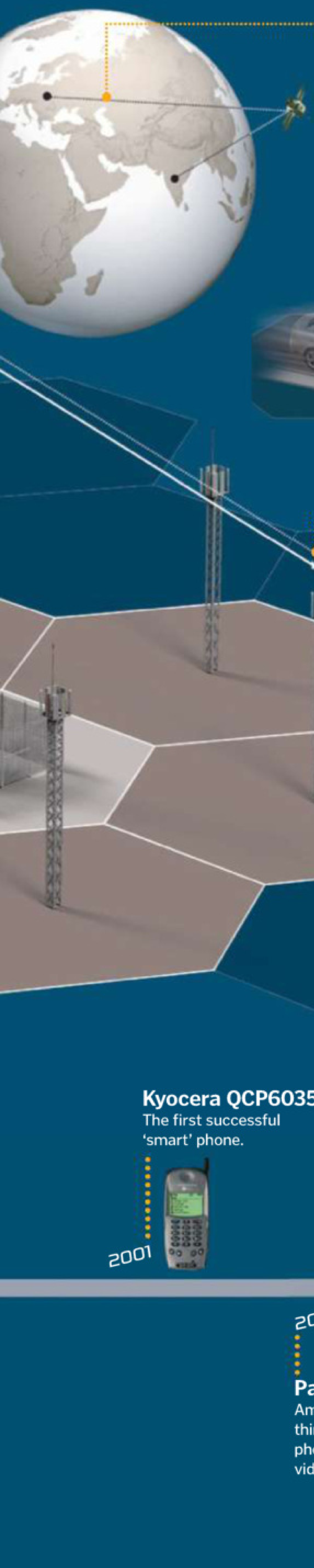
Buy Phone
2 Up until June 2014, 500 million iPhones have been sold worldwide, from the original launch in 2007 to the latest 5S model released in late-2013.

First to phone
3 Motorola engineer Marty Cooper made the first public mobile phone call. When he made it on 3 April 1973 his first words were to mock a rival telecoms engineer.

Price drop
4 The first-ever mobile phones cost over £2,300 ($3,500) but were still hugely popular with people who were on the go, even though coverage was much more limited.

Half the world away
5 There are six billion registered mobile phones across the globe, so there's nearly one for every person on the planet, although multi-mobiled people do skew that statistic.

DID YOU KNOW? *The best-selling mobile phone in history was the Nokia 1100, with over 250 million sold*



Going international
When making a very long-distance call, satellites are used to bridge the gap. This is why there is often a delay as the signal has to travel much farther.

On the move
If you have come into range of another mast before leaving another, it transfers seamlessly.

Connecting
The local cell site antenna establishes communication with the recipient's phone. When you start talking, vibrations are turned into electrical signals.

The recipient
The electrical signal is turned back into vibrations by the target phone, which enter the recipient's ear as sound.

Kyocera QCP6035
2001
The first successful 'smart' phone.

Panasonic P2101V
2001
Among the first third-generation cell phones (with videoconferencing).

Motorola ROKR
2005
First cell phone with iTunes.

iPhone
2007
It has a 8.9-cm (3.5-in) touchscreen and Wi-Fi Web access.

App attack

Apps are a crucial part of the modern mobile phone. It's estimated that the app market is worth a staggering £14.6 billion ($25 billion) worldwide, but which have had the biggest impact on the mobile scene?

Biggest buzz
The simple but insanely difficult *Flappy Bird* was an incredible success, netting independent creator Dong Nguyen £29,200 ($50,000) per day through advertising alone. He eventually took it down after he couldn't deal with the sudden pressure and fame.

Most downloaded
Probably the most famous app of all time, *Angry Birds* has been downloaded more than two billion times since it launched in December 2009. It has since spawned a cartoon series, console games and a planned feature film.

Highest grossing
Strategy and battle app *Clash Of Clans* has been at the top of the most recent charts in terms of revenue, gaining around £700,000 ($1.2 million) per day. However, *WhatsApp* netted its founders £11 billion ($19 billion) when they sold it to Facebook in 2014, dwarfing *Clash Of Clans'* cumulative revenue.

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SUPER COMPUTERS

THE FASTEST & MOST POWERFUL COMPUTERS ON EARTH

• 15 YEARS OF CALCULATIONS IN ONE SECOND • 83,000 PROCESSORS • AS POWERFUL AS 715,000 iPADS

If you gave everyone in the UK a calculator and set them doing sums at the rate of one every second, it would take 15 years of combined, non-stop calculation to manage what the fastest supercomputer in the world can do in just one second. And yet the basic chips that power this mathematical monster are virtually the same as the CPU in your home PC.

The first supercomputers were built just as vacuum valve technology was beginning to be replaced with transistors. Manchester University installed one of the very first in 1962; a machine called Atlas. This computer had as much processing power as every other computer in the UK combined. In the USA, a company called CDC dominated the market for supercomputers for most of the 1960s. The CDC 6600 was ten times faster than its nearest competitor and the company sold 100 of them for $8 million each. The genius behind these computers was a man called Seymour Cray. When Cray left to form his own company in 1972, the supercomputer business jumped up a gear. The Cray-1 was the first to use integrated circuits (computer chips) instead of separate transistors. A lot of its speed came from a

5 TOP FACTS
FASTEST COMPUTERS

Tianhe-2 – 33,863 Tflops

1 Tianhe means Milky Way. 1,300 scientists and engineers collaborated to build it. There are 3,120,000 computing cores altogether, occupying 720m² (7,750ft²) of floor space.

Titan – 17,590 Tflops

2 Housed in 200 cabinets, Titan uses 8.2MW of power - as much as 2,000 private households. The cooling fans are so loud that staff have to wear ear protection.

Sequoia – 17,173 Tflops

3 It has modelled the electrical activity of the human heart and simulated 3.6 trillion stars in the cosmos. Sequoia was the first computer to use a million cores at once.

K Comp – 10,510 Tflops

4 Named after the Japanese word 'kei' which means ten quadrillion, in 2011 the K Computer became the first in the world to exceed 10,000 Tflops in size.

Mira - 8,587 Tflops

5 Based at the Argonne National Laboratory, outside Chicago. In one day it can perform as many calculations as a desktop computer would manage in 20 years.

DID YOU KNOW? *The USA is home to 233 of the top 500 supercomputers. China has 76, the UK has 30*

technique known as vector processing. It exploits the fact that most supercomputer applications run the same few calculations over and over across a huge dataset stored in memory. Traditionally, computers would fetch the first datapoint from memory, perform all the calculations, write the result back to memory and then fetch the next datapoint and repeat the entire process. The Cray-1 treated the operation like a factory assembly line, continuously feeding in data at one end and writing it back out at the other end. This ensured all circuits were busy all the time, instead of spending a while waiting for the next piece of data. The Cray-1 was ultimately succeeded by the Cray-2 in 1985, which remained the fastest computer in the world until 1990.

Vector processing depends on your ability to move data rapidly through the processor and most of the performance of the Cray-2 was simply due to the much faster memory chips it used. In the 1990s, supercomputer designers tried a different tack. Instead of having just a handful of processors (the Cray-2 had just eight) sharing a common pool of memory, they gave each processor its own private memory and arranged large numbers of them in a grid. Called mesh computing, this system connected each processor to its four immediate neighbours using network technology. When processors want to exchange data, they send it as a network message. Although this is slower than wiring the processors directly together, they can operate more independently and don't need to communicate as often. This makes the system much more scalable – you can make your supercomputer faster simply by adding more processors to the mesh.

Since 1993, the world's fastest supercomputers have been ranked at www.top500.org using a benchmarking program that measures computer speed as the number of floating-point operations per second, or flops. Floating-point operations are essentially maths calculations that involve numbers with a decimal point. If you could work out the answer to a sum such as 12.83224 x 619.113 in one second, your brain would be running at a single flop. Modern supercomputers are measured in teraflops (Tflops) or thousands of billions of flops. The ten fastest computers on the Top500 list are all petaflops machines – a staggering thousands of teraflops in size. And they might be getting faster still.

Q&A: Dr Alan Simpson, technical director

ARCHER's technical director reveals what the supercomputer's capable of

ARCHER is the most powerful supercomputer in the UK, currently ranked 25th in the world. It's hosted at Edinburgh University and we spoke to Dr Alan Simpson, who is the technical director of the Edinburgh Parallel Computing Centre.

What is the supercomputer ARCHER primarily used for?
ARCHER is used for materials and chemistry, engineering and environmental science. Example applications [for the supercomputer] include: longer-lasting smartphone batteries, quieter, [designing] more efficient aeroplanes and understanding climate change.

How does it compare to its predecessor?
ARCHER is capable of performing at least three times more computational research than its predecessor, HECToR.

Why does Edinburgh need its own supercomputer?
ARCHER is the national HPC [High Performance Computing] system for the United Kingdom and provides computational resources for nearly all the major UK research universities.

How many people have access to ARCHER?
ARCHER will have more than 3,000 users from more than 50 research institutions across the UK.

How many simulations are running on it at any one time?
Typically, more than 100 simulation jobs of varying sizes run at the same time, although some jobs take up the full system.

How much space does ARCHER take up?
ARCHER is made up of 16 cabinets, each of which is roughly the size of a wardrobe.

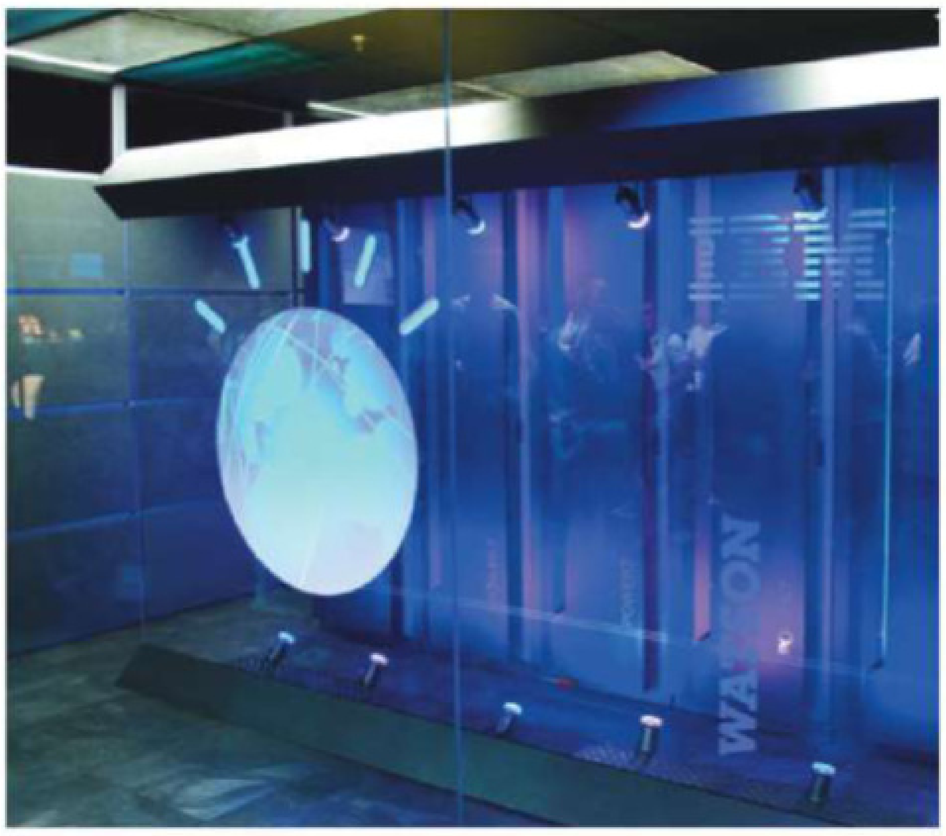
How much electricity does it use to run and to keep it cool?
It uses more than 1MW of electricity. ARCHER is housed in a specially designed building that minimises electricity used in overheads, particularly chilling. As Edinburgh has a cool climate for much of the year, we are able to exploit 'free cooling', ie passive cooling of water to the atmosphere.

What is your role within the ARCHER project?
I lead the teams providing science support and user support.

How long is it expected to last before it is replaced with something better?
The initial contracts for ARCHER are for four years. UK national HPC services typically last between four and eight years.

How many staff are required to run and maintain ARCHER?
There are two Cray engineers on site plus around five University of Edinburgh systems staff. There are also a significant number of staff involved in the service desk and in-depth computational science and engineering support.

What operating system does it use?
ARCHER uses Cray Linux Environment (CLE), a proprietary version of Linux.



Modern supercomputers now use tens of thousands of processors. The only way to build them cost effectively is to use off-the-shelf components – most of the ten fastest supercomputers in the world use high-end variants of the Intel processors in your desktop PC. The newest ones use the graphics processing units (GPUs) found on your computer's graphics card too, but they don't use them for running video games. GPUs are very good at vector processing and by combining a CPU and a GPU into a single computing unit, hybrid supercomputers are able to gain the advantages of vector processing and mesh computing at the same time. GPUs now account for about 90 per cent of the processing performance of the fastest supercomputers and allow them to run ten times as fast as the previous generation, while only consuming about twice the power.

Supercomputer applications are written in the Fortran, C++ and Java programming languages, but programming massively parallel supercomputers is nothing like writing software for a Windows PC. In order to harness all the processors, you need to be able to break up your problem into smaller pieces that can be distributed among them.

If you are modelling the stars in the universe or the flow of air molecules over a turbine blade, you can't simply assign each processor to a different star or molecule because the calculations from one point in the simulation affect those around it.

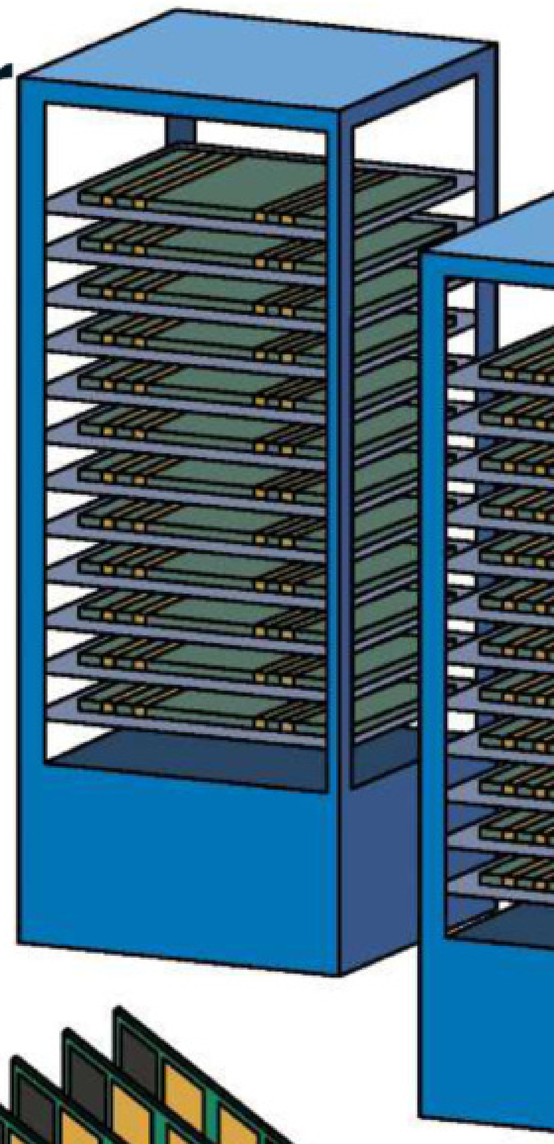
The Global Address Space Programming Interface (GPI) is a new programming tool that allows each processor to treat all the memory on all the processors as a single shared pool. The GPI handles the work of sending the right messages to keep each processor up to date at all times, leaving the research scientist to get on with defining how the simulation should run, making the supercomputer more efficient.

Getting access

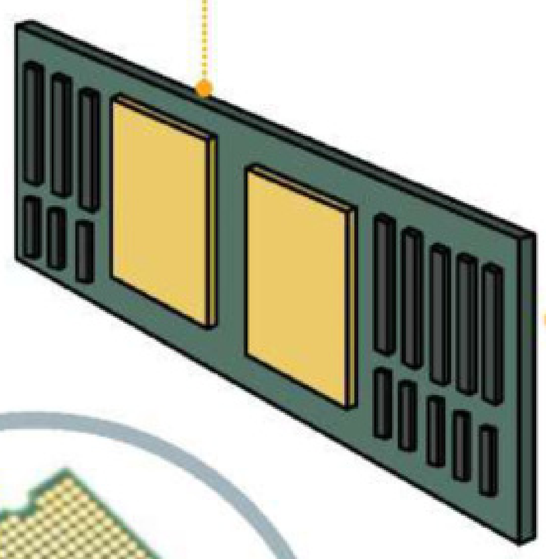
If you want to run your simulation on one of the really big supercomputers you'll need to write a proposal. Once a year, a vetting committee checks whether the science value is justified and the computer code is free of bugs. Your program should need at least 20 per cent of the total power of the supercomputer; otherwise it could just as well run on a smaller supercomputer. If you are a research scientist, access to the supercomputer is free, but you'll have to publish the results for everyone to use. Private companies pay for each processor they use and for each hour the simulation runs.

Anatomy of a supercomputer

Tianhe-2 is the fastest supercomputer in the world. How is it put together?

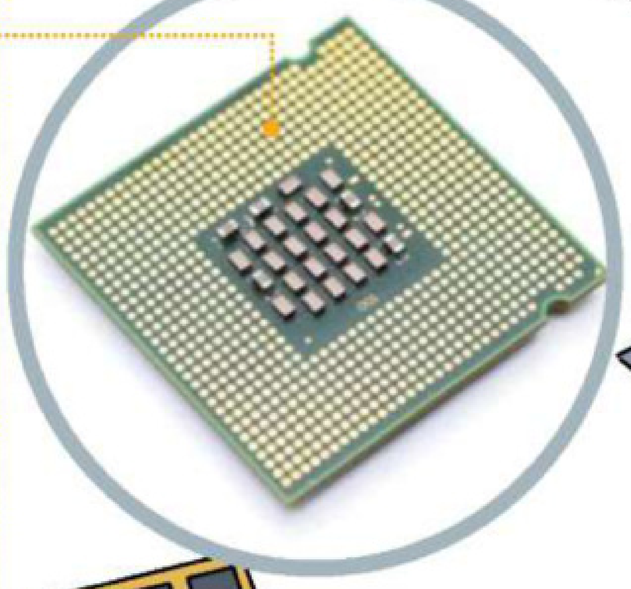


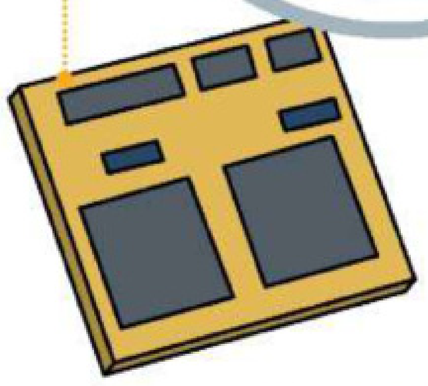
Compute blade
Each compute card is paired with another card containing five more Xeon Phi chips and 128GB of memory.
= 92 iPads

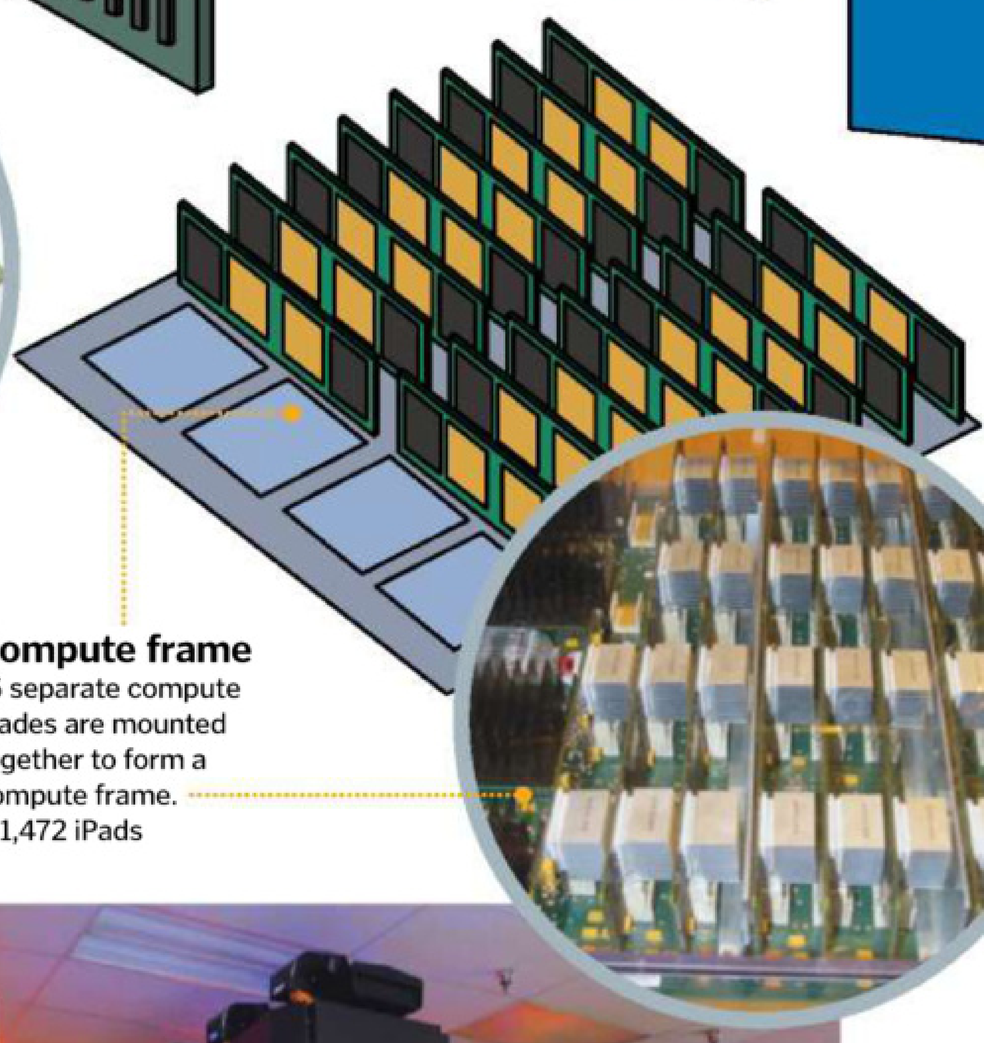


Compute card
Four of these processors are combined on a single circuit board with an Intel Xeon Phi parallel processing module.
= 26 iPads

Chip
The basic building block of Tianhe-2 is the Intel Ivy Bridge Xeon processor. Each chip has 12 parallel computing cores.
= Three iPads







Compute frame
16 separate compute blades are mounted together to form a compute frame.
= 1,472 iPads

An IT engineer configuring servers

NASA's Discover Supercomputer has almost 15,000 processors

13 TRILLION

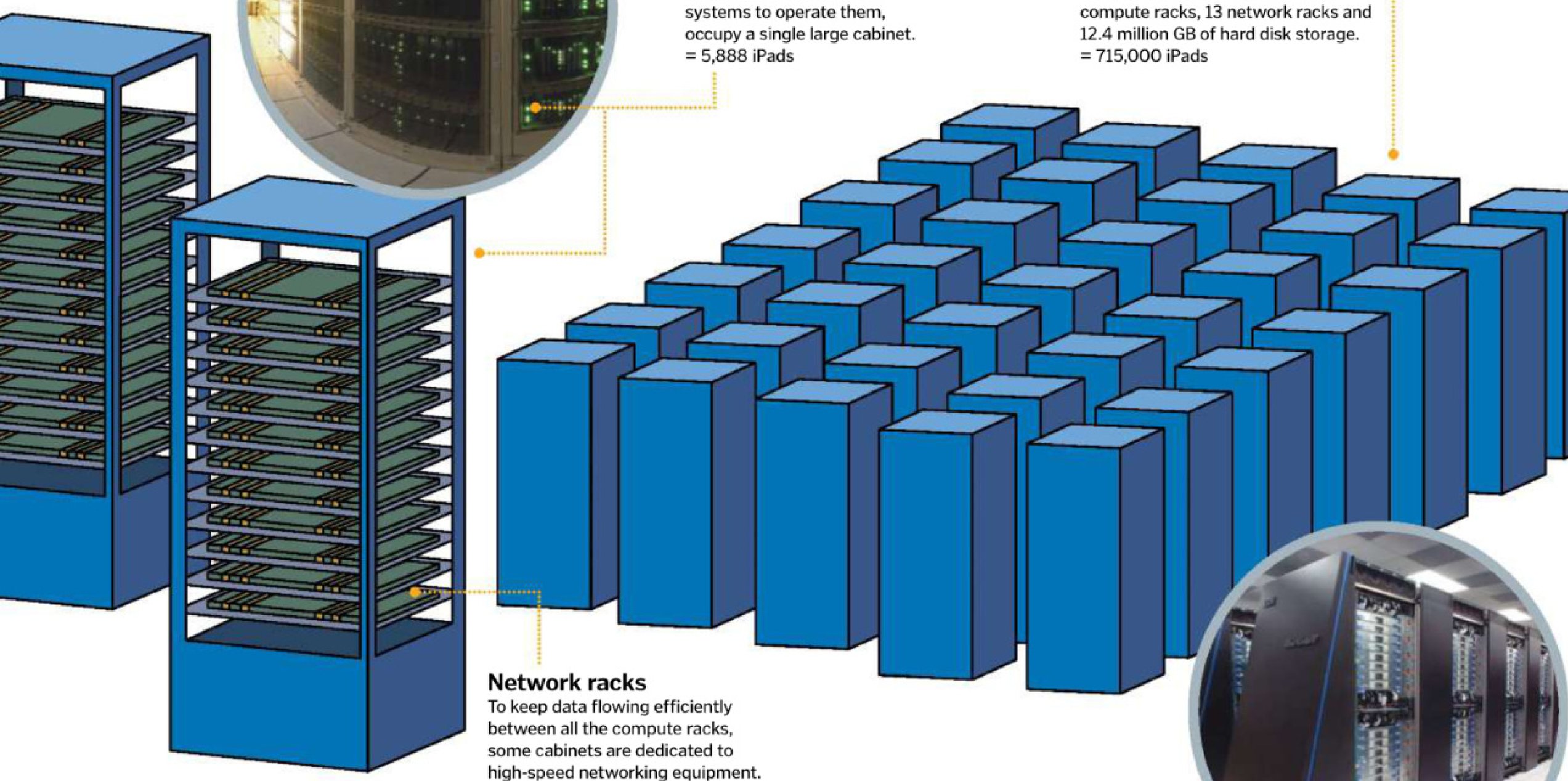
LARGEST SIMULATION

The largest fluid dynamics simulation ever used 13 trillion simulation 'cells' to model the behaviour of 15,000 bubbles on the Sequoia supercomputer at Lawrence Livermore National Laboratory in the USA.

DID YOU KNOW? *The #3 supercomputer in the world, Sequoia, uses as much power as 2 million laptops!*

Compute rack
Four compute frames, plus the power supply and cooling systems to operate them, occupy a single large cabinet.
= 5,888 iPads

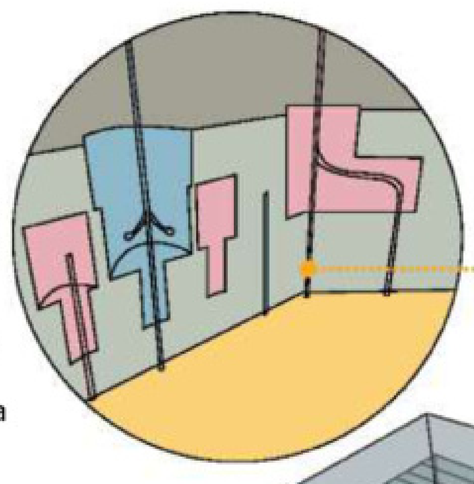
Network racks
Supercomputer
The full Tianhe-2 system has 125 compute racks, 13 network racks and 12.4 million GB of hard disk storage.
= 715,000 iPads



Network racks
To keep data flowing efficiently between all the compute racks, some cabinets are dedicated to high-speed networking equipment.

How Aquasar keeps cool

All processors generate waste heat. Left uncooled, the CPU in your desktop computer would get dangerously hot and could damage components. To prevent this, the heat is dissipated through radiator fins, which are cooled with a fan. But in a supercomputer, blowing air fast enough over all the processors in all of the cabinets can be tricky. Water cooling is more efficient because it takes a lot more energy to raise the temperature of water than air, but water is conductible so it has to be contained within leak-tight cooling pipes. The new SGI ICE X supercomputer sidesteps this by using a fluorine-based coolant called Novec, which was developed by 3M. This fluid conducts heat well but is electrically insulating, so it can be pumped directly over live circuit boards. Cooling this way uses just five per cent of the electricity of air cooling and takes up ten times less space than water cooling.

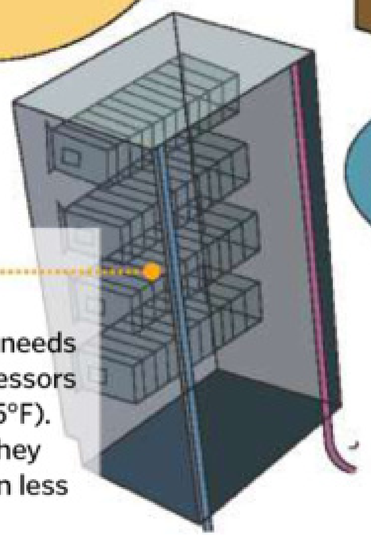


Hot water
Network of very fine, branching channels is mounted on the back of each processor. The flowing water absorbs heat.

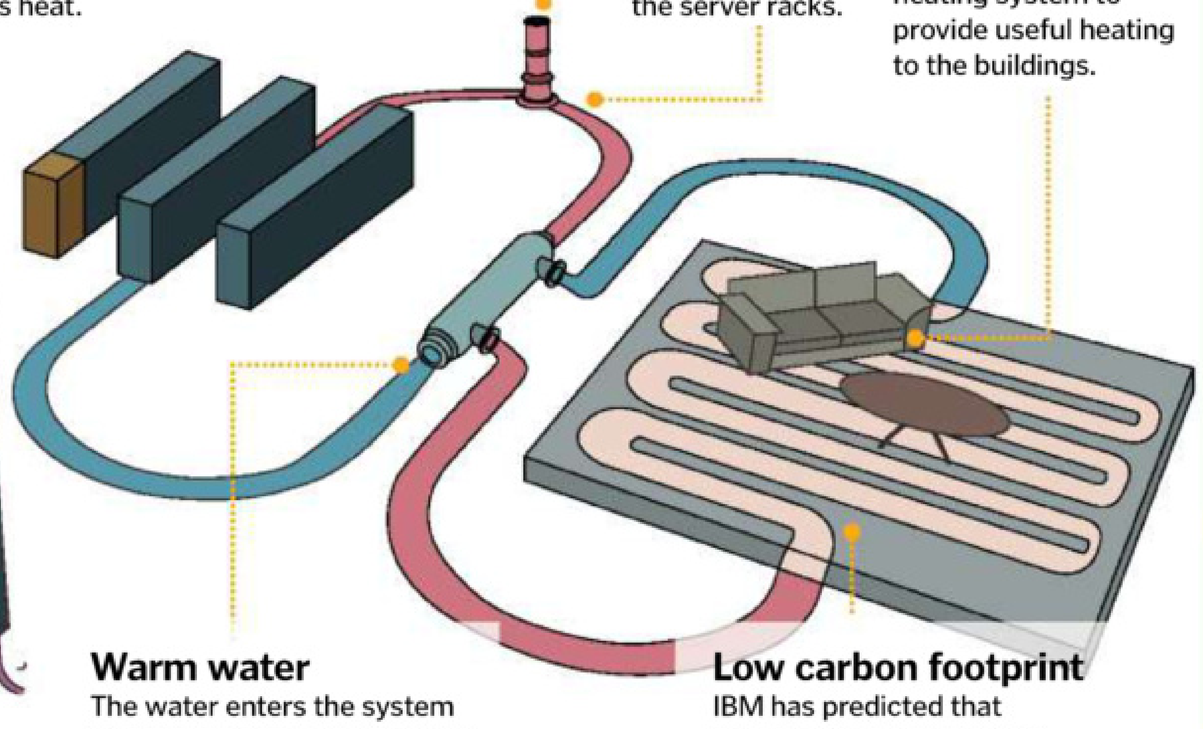
Pump
The supercomputer uses 10l (2.6gal) of water in its own closed loop and this circulates three times per minute.

Heat exchanger
The hot water heats the water in a second larger circuit that connects all the server racks.

Recycled heat
The outer circuit is fed into the university's heating system to provide useful heating to the buildings.



Hot chips
The Aquasar supercomputer needs to keep its processors below 85°C (185°F). Left uncooled, they would blow up in less than a second.

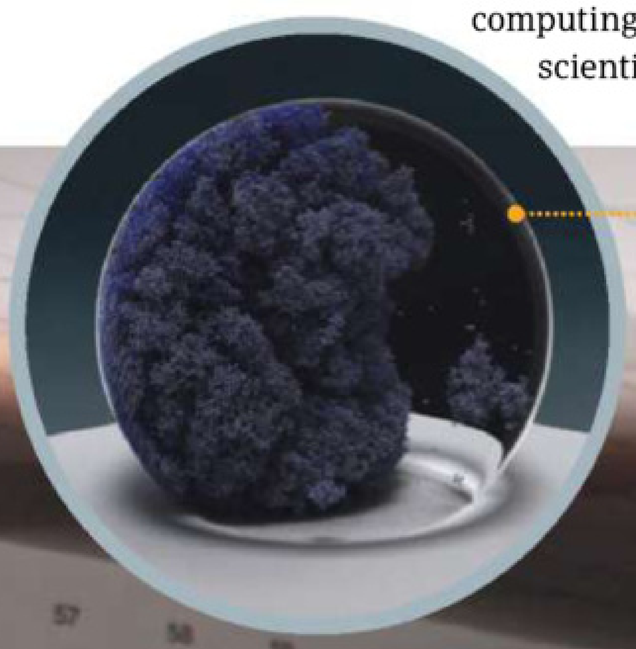


Warm water
The water enters the system at 60°C (140°F) and is heated to 65°C (149°F) while passing through the supercomputer.

Low carbon footprint
IBM has predicted that liquid-cooled systems will lower the carbon footprint by 85 per cent.

Supercomputers

China, India and the USA are all committed to building an exaflops supercomputer by 2018. That's 1,000 petaflops, or about 30 times faster than the Chinese Tianhe-2 supercomputer, which is currently the world's fastest. Exaflops computing would allow scientists to finally model the human brain right down to a perfect simulation of each neuron, but the limiting factor right now isn't just money; it's electrical power. Tianhe-2 uses 24 megawatts of power. In the UK, the electricity bill for a machine this size would be over £21 million ($36 million) a year. Scaling this up to an exaflops supercomputer (1,000 petaflops) would require a large proportion of the output of a typical coal-fired power plant! However impressive the number-crunching abilities of supercomputers are, it seems they still can't match the energy efficiency of a brain. Maybe there's still a use for humans after all.



A visualisation of a water droplet simulation performed by the Titan supercomputer for GE

The Titan supercomputer is made up of several banks and rows of individual units

Nuclear energy

Denovo

Nuclear reactor technicians need to be able to able to predict the distribution of neutrons within the reactor core in order to make sure the nuclear fuel is burning uniformly.

Titan uses Denovo to simulate the complete state of a nuclear reactor core in just 13 hours. The data from this will allow the USA to extend the life of its ageing nuclear reactors, which currently supply approximately one-fifth of the country's electricity.

Molecular dynamics

LAMMPS

LAMMPS stands for Large-scale Atomic/ Molecular Massively Parallel Simulator. An open-source program, it will run on an ordinary Windows PC. But it has been specifically optimised to scale well on the huge number of parallel processors in supercomputers. It uses Newton's equations of motion to model the forces between billions of atoms, molecules or larger particles at once. It's used for anything from nanotechnology to welding research.

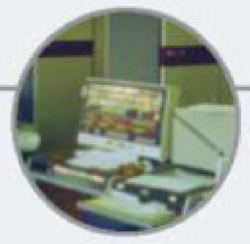
Climate modelling

CAM-SE

CAM-SE models the atmosphere of the entire planet, divided into cells of 14km^2 (5mi^2)and with 26 vertical layers. It simulates the movement of wind, water vapour, carbon dioxide and ozone, including the chemical reactions that occur at different temperatures and altitudes. Titan can model more than two years of simulation time in a single day. This allows scientists to predict the effects of global warming, ozone depletion and refine long-term weather predictions.

KEY DATES
THE RISE OF THE SUPERCOMPUTER

1962
Atlas is installed at Manchester University. It was one of the first supercomputers.



1979
The Linpack benchmark is used to compare the speed of the most powerful supercomputers.

1985
The Cray-2 is built. It has more memory than every other Cray computer built to date combined.

1996
IBM's ASCI Red becomes the first to break the teraflops barrier and is the most reliable supercomputer ever built.

DID YOU KNOW? *Pangea owned by oil company Total, uses 120km (74.6mi) of fibre-optic cable to connect its processors*

Combustion efficiency
S3D
S3D simulates the behaviour of burning hydrocarbons very precisely. This allows fuel injection systems for diesel and biofuel engines to be fine tuned so that they produce exactly the right pattern of fuel droplets to allow them to autoignite on each stroke of the engine's pistons. Jaguar was the first supercomputer to achieve a full simulation and Titan will continue this to even greater levels of precision. This will allow engineers to design more efficient engines.

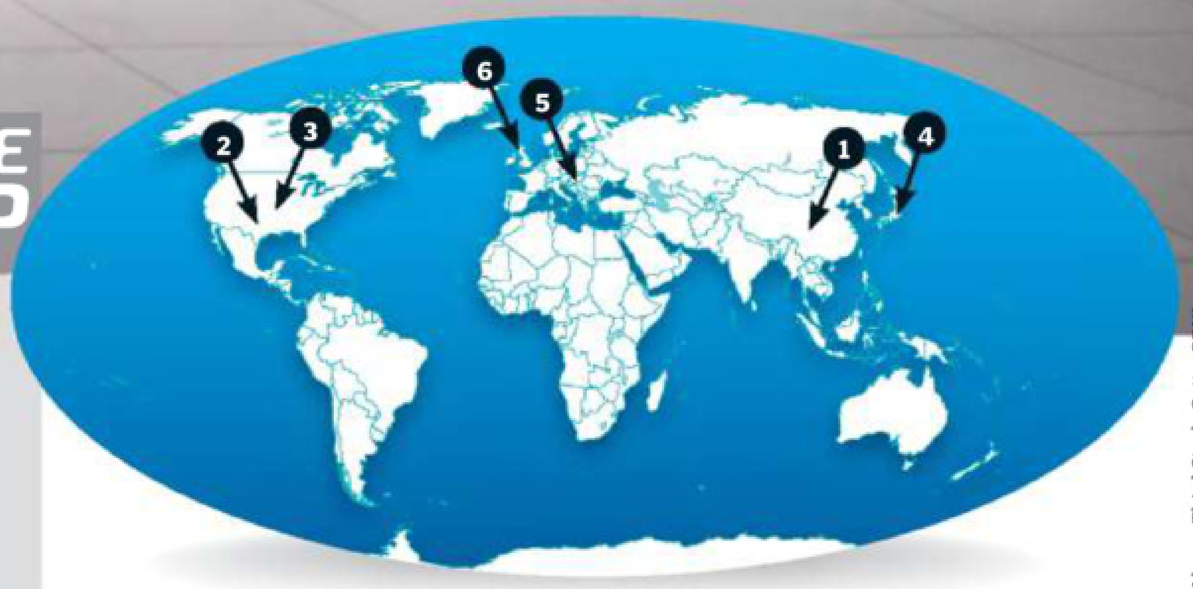
Hard disks
WL-LSMS
Computer hard disks and electric motors rely on magnetic materials. The WL-LSMS gets its name from the two algorithms it uses to study the interactions between the electrons and atoms in these magnets: Locally Self-consistent Multiple Scattering and the Wang-Landau algorithm, named after the physicists that developed it. By combining both algorithms, the simulation can accurately represent the behaviour of magnetic materials down to the quantum level at temperatures just above absolute zero.

A technician working on upgrading Titan – a job that never stops

Radiation
NRDF
This application models the way that uncharged particles travel. The most important use for this is to simulate electromagnetic radiation in astrophysics, laser fusion and medical imaging. The NRDF application is also used as a testbed to develop new ways to program supercomputers, using algorithms that concentrate the processor power on the most important parts of the simulation and so allow it to model even larger and more complex systems.

ON THE MAP

Supercomputer spotting
1 Tianhe-2
2 Titan
3 Sequoia
4 K Computer
5 Piz Daint
6 ARCHER



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Trekker cameras

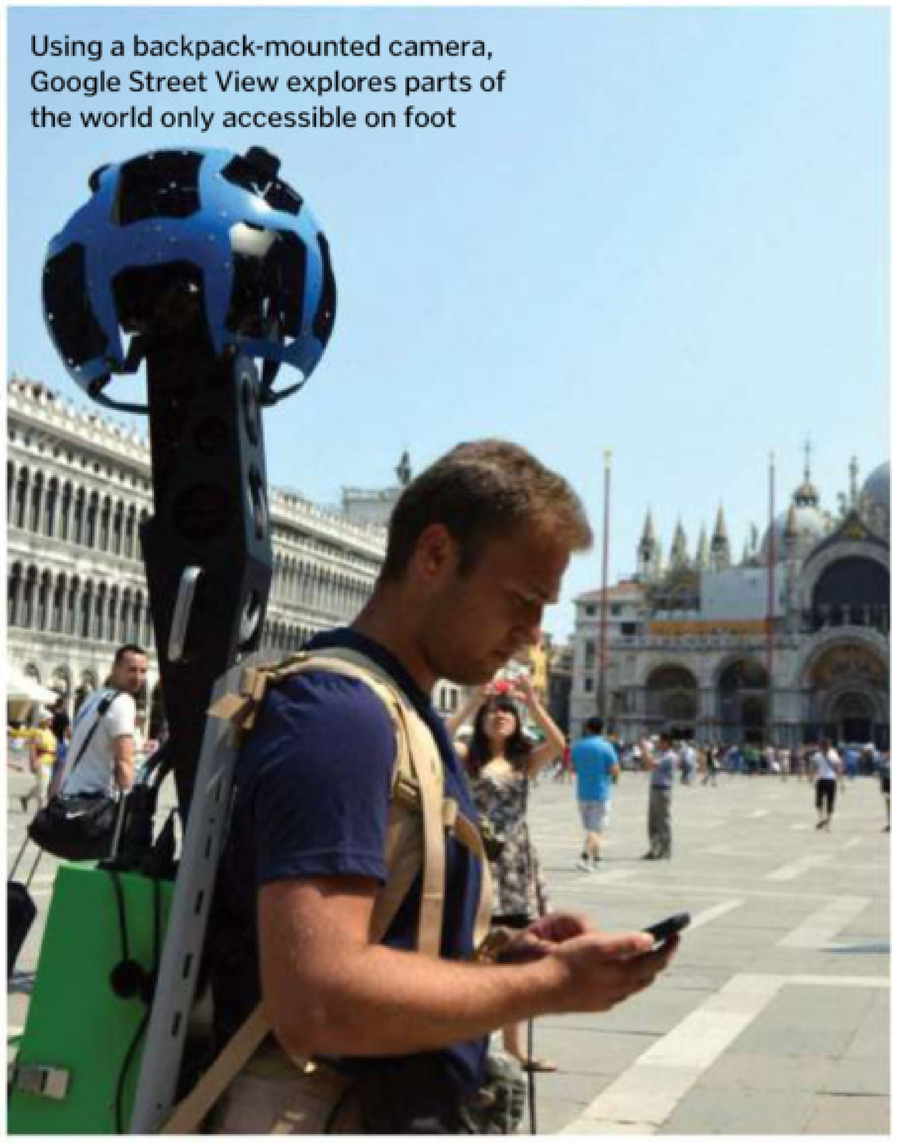
Google Street View can now venture into city centres and the remote wilderness with its tough camera backpacks

A fleet of Google Street View cars has been capturing panoramic images of our roads and buildings for some time now, but there are certain areas they haven't been able to reach. Well, until now.

The solution lies in a 1.2-metre (four-foot)-tall, backpack-mounted camera called the Trekker. Kitted out with 15 lenses – each attached to a five-megapixel camera – it takes a photograph every 2.5 seconds, sweeping in a full panorama.

It weighs a hefty 19 kilograms (42 pounds), but volunteers seem very keen to take it into the wilderness. Charitable organisations, research institutions and the tourism industry are all eligible to apply to borrow the Trekker equipment, giving Google access to areas unreachable by their car-mounted cameras, and eventually allowing people to virtually explore national parks, ruined buildings and other difficult-to-reach areas like canyons and caves.

The equipment has already been used to map several hiking trails, including the Grand Canyon, and in the UK the complex network of canals and waterways has been recorded.



Using a backpack-mounted camera, Google Street View explores parts of the world only accessible on foot

Making maps

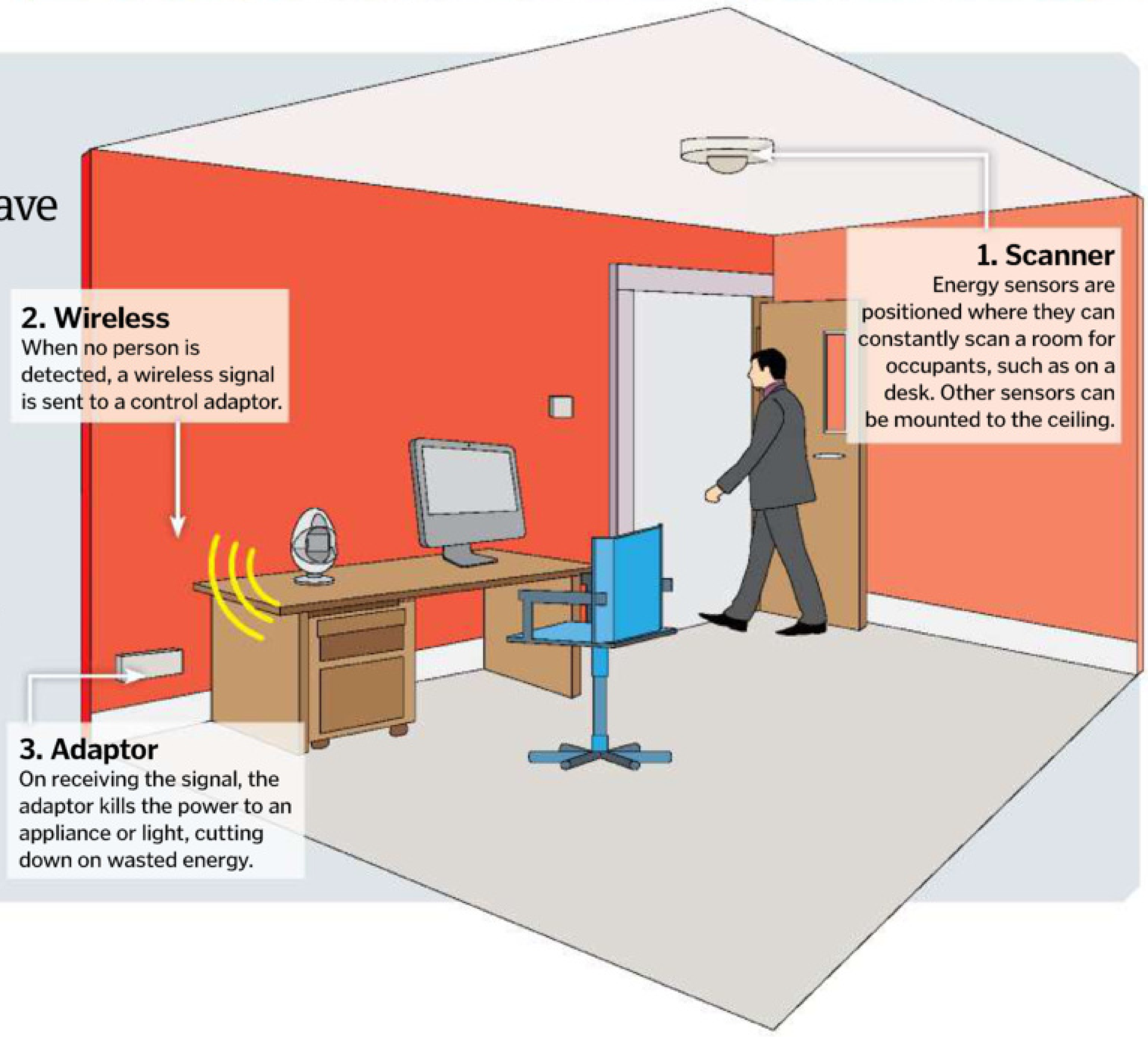
Google is extremely selective when it comes to imagery and aims to ensure that photographs are captured when the weather is clear and the view is as unobstructed as possible. Images are recorded alongside GPS information in order to ensure that their exact location is accurately mapped.

Google's camera technology uses a series of lasers to measure the distance from the lens to the subject of the image. These in turn create 3D models of the landscape that enable the best image to be selected depending on where the user is virtually positioned within Street View.

Eco sensors

Meet the gadgets helping to save the planet and our money

Smart energy-saving devices can detect when a room is empty using motion sensors and then turn off appliances through a control switch if no one is present. Some sensors detect body heat, while others send out waves (ultrasonic, microwave or radio) that reflect off any moving object. The former are generally preferred for energy-saving devices, as they can distinguish whether someone is standing or sitting still. When no person is detected, a signal is sent to a control box that is attached to an appliance – normally a plug socket or light switch – to turn it off. For convenience, most devices also have a time delay, so leaving the room briefly will not instantly turn off all your appliances.



© Alamy; Google

Inside the Steam Machine

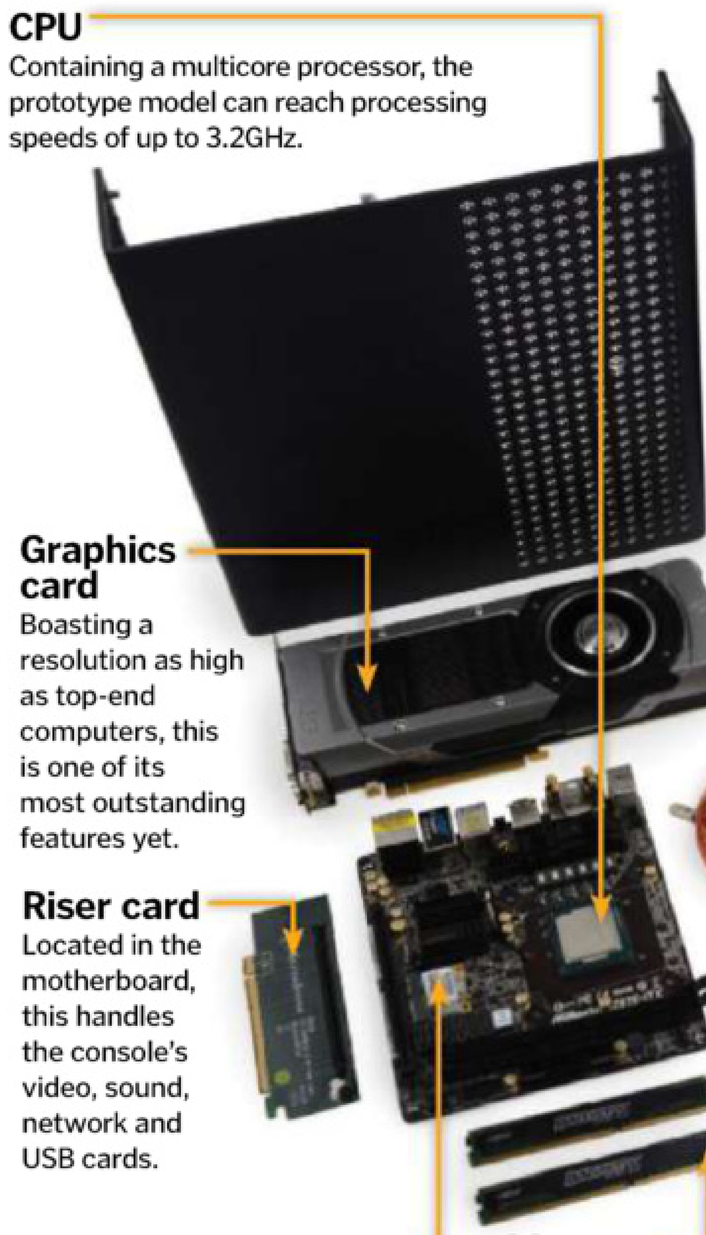
Meet the ambitious new computer aiming to bridge the gap between console and PC gaming

The Valve Corporation is renowned for its Steam system, which distributes and manages PC, OS X and Linux gaming. Its new project, the Steam Machine, looks to revolutionise videogaming as we know it.

Designed to be a link between eighth-generation consoles and PC gaming, editing and changing the Steam Machine is actively encouraged so it can cater for your specific needs. With this in mind, unlike the Wii U, Xbox One and PlayStation 4, the console – like a PC – will have interchangeable graphics cards. Hardcore gamers can plump for the full-HD resolution Nvidia GTX Titan while more recreational users could opt for the GTX 660, which has specs equivalent to the current consoles on the market.

A controller will provide a middle ground between a console gamepad and a laptop trackpad with 16 configurable buttons and a touchscreen, aiming to simplify the PC Steam system and appeal to a broad range of gamers.

The only issue is whether games developers will up sticks and move from established formats to an unknown console, but with the stunning hardware on offer, there's no doubt many will be swayed sooner or later. 300 units are currently available to testers and the next wave of Steam Machines is scheduled for release toward the end of 2014, with models varying from as low as £300 ($500) right up to £3,570 ($6,000).



CPU
Containing a multicore processor, the prototype model can reach processing speeds of up to 3.2GHz.

Graphics card
Boasting a resolution as high as top-end computers, this is one of its most outstanding features yet.

Riser card
Located in the motherboard, this handles the console's video, sound, network and USB cards.

Motherboard
The machine's main hub, it contains a DisplayPort, DVI, USB and HDMI ports, RAM as well as a graphics card.

Memory
With 16GB of RAM in the CPU and 3GB in the GPU, the Steam Machine shouldn't experience any sort of lag.

Controller
A fusion of a keyboard and a console controller, it is wired rather than battery powered and has 16 configurable buttons and a touchpad.

Shell
Sturdy but easily opened, the case is held on by only one screw to allow for quick and easy modification.

Power supply
The prototype contains a 450W 80 Plus power supply that has a gold-level electrical efficiency.

Power switch
Dominating the front panel, its edge and centre is lit up by 12 LEDs.

Hard drive
The 1TB Seagate Laptop SSHD will look after all your media, from HD games to your music library and favourite films.

Fan
The Steam Machine has a Zalman CNPS 2X Mini-ITX for cooling, which is efficient yet quiet.

Three Steam rivals

1 Falcon Northwest Tiki

A staggering £3,570 ($6,000) for a full-spec model with all the trimmings of 6TB storage and 16GB RAM. Adorned with glossy artwork and an Intel Core i7, this could prove to be one of the best Steam Machines.

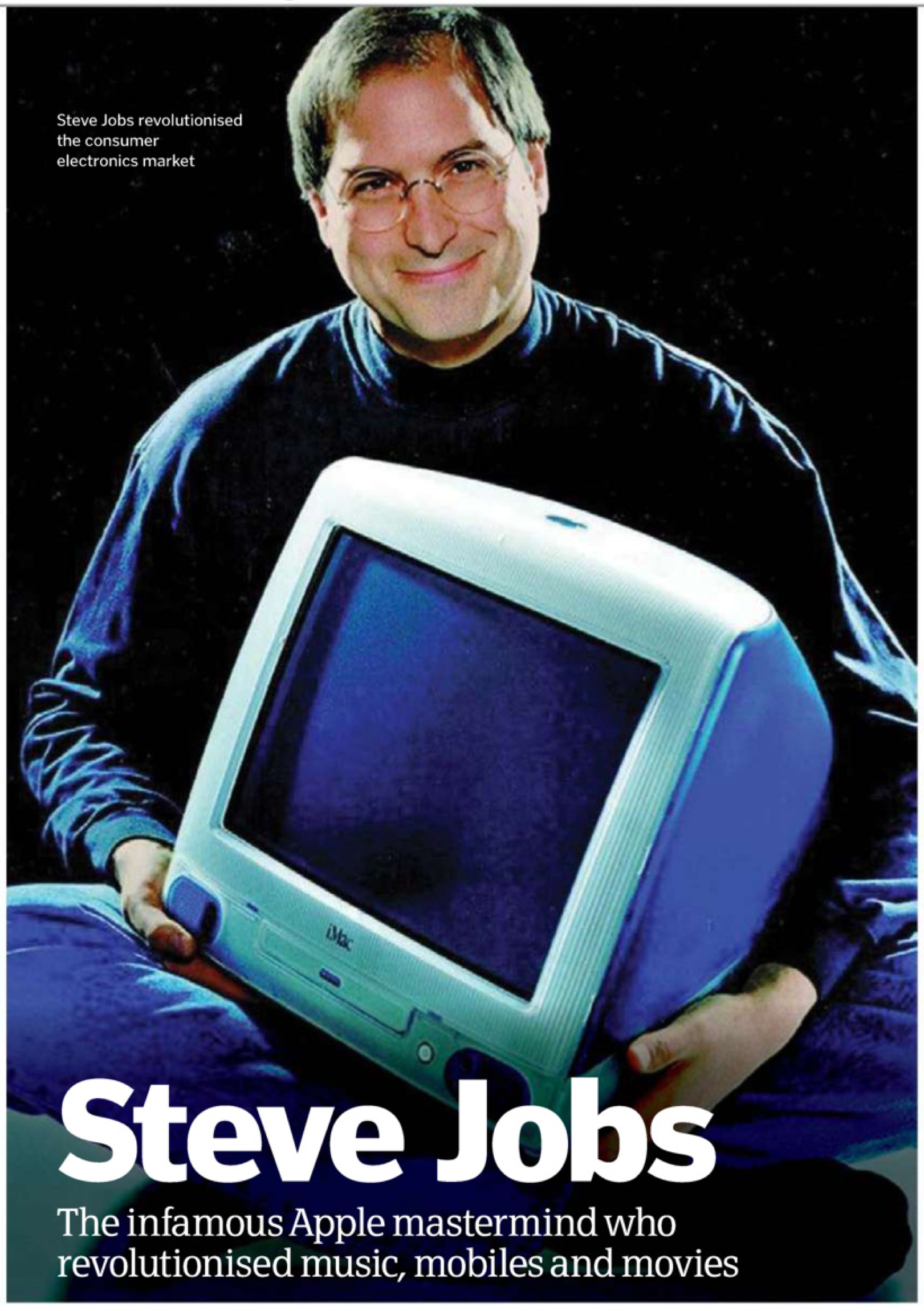
2 Alienware

A subsidiary of computer giant Dell, the Alienware model will be competitively priced and similarly powered to the PS4 and Xbox One. Like all Steam Machines, however, its ultimate success will be dependent on getting the games developers to jump on board the Steam Machine bandwagon.

3 Bolt II

Made by Digital Storm, the Bolt II is a good all-rounder with a GTX 780 Ti graphics card and a 1TB hard drive, and it also looks the part with a sleek design. An upgrade of the original Bolt, the fans you can see are part of an advanced thermal liquid cooling system to keep it cool and quiet.

© IFixit.com; Falcon Northwest; Dell Inc; Digital Storm



Steve Jobs revolutionised the consumer electronics market

Steve Jobs

The infamous Apple mastermind who revolutionised music, mobiles and movies

Steve Jobs was one of the most controversial figures of the late-20th and early-21st century. Though he was criticised for his autocratic leadership, unrelenting perfectionism and greed, his consumer insight enabled him to build one of the planet's most recognisable brands and gather a near-religious following.

Jobs was born in 1955 in San Francisco. He was adopted by Paul and Clara Jobs, a working-class couple living in Silicon Valley. While at high school, he took up a summer job at Hewlett Packard where his passion for technology grew. It was during this time that he met Steve Wozniak, and on graduating the pair began building a computer in his parents' garage. With Wozniak's technical genius and Jobs' innovation, they were able to build a new type of personal computer. The Apple I, which went on sale in 1976, came complete and worked straight out of the box. In the dawn of the personal computing boom, it was an instant success, and sales of the second model skyrocketed. Apple Computer, Inc was born.

But Jobs' prosperity at Apple was short-lived. The Macintosh model failed to take off and three of the six Apple factories were shut down. Jobs' autocratic style of leadership also led to an internal power struggle, and in 1985 he left Apple. Instead, Jobs founded a company called NeXT that built workstations for the higher-education market. He also bought Graphics Group, which made high-end hardware for computer-animated films. Jobs transformed it into a studio, renamed it Pixar, and turned it into one of the biggest names in the film industry.

Meanwhile, Apple was teetering on the brink of bankruptcy. The launch of the much more

"With the Mac battling for survival in a Windows world, Jobs decided on a different direction"

The life of Jobs

Steve Jobs' path from birth to success wasn't straight and easy

1955
Jobs is born to two unmarried students, and adopted by Paul and Clara Jobs.

1972
Jobs takes a job as a technician at Atari, a successful videogame and home computer company.

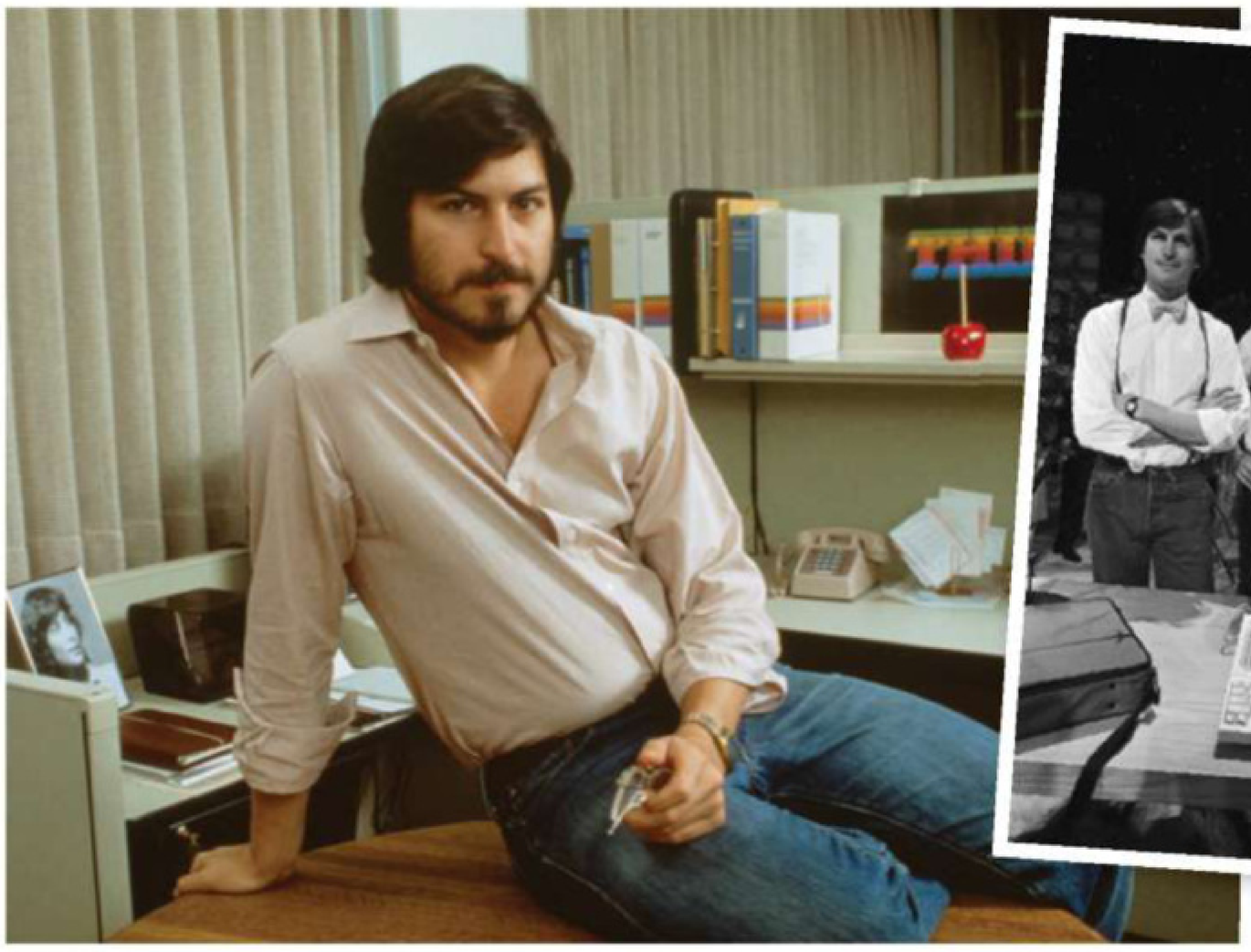
1974
Travels to India, where he converts to Buddhism, becomes a vegetarian and experiments with psychedelic drugs.

1976
Together with his friend Steve Wozniak, he builds the very first Apple I computer in his parents' garage.

The big idea

Why was the iPod so successful?

In 2000, Apple was surviving but not thriving. The release of the iPod in 2001 changed all this. But what made it stand out from all the other MP3 players on the market? First, the iPod was incredibly easy to use. With only five buttons, a click wheel and a simple menu, it was easy to operate and navigate, as well as arguably being the most stylish player on the market. It also did a really good job of integrating the player, the computer and the software, and was Windows-compatible as well. Along with the launch of iTunes, these all equated to an unparalleled success story.



affordable Windows 95 meant the mouse and graphical user interface were now industry standards, and Apple's turnover plummeted. Despite this, in 1996 Apple paid more than $400 million for NeXT and Jobs returned to Apple.

With the Mac battling for survival in a Windows world, Jobs decided it was time to take a different direction. In 2001, he unveiled the iPod – a sleek, statement device that met the demand for music on the move and was to become the best-selling portable music player of all time. This was followed by the launch of the iTunes music store in 2003. In 2007, thousands of devoted Applites (the nickname for devoted Apple fans) queued for blocks to get their hands on Jobs' latest brainchild: the iPhone. By 2010, Apple had sold almost 90 million of them.

In October 2011 Jobs died from complications of pancreatic cancer, leaving Apple the second-most valuable company in the world with £50 billion ($80 billion) in the bank. His mark had been well and truly engraved into the company, and remains on the property of millions of people around the world.

ABOVE LEFT
A young Steve Jobs in his office at Apple

ABOVE RIGHT
Jobs (left) with Sculley and Wozniak in 1984

Top 5 facts: Steve Jobs

1 Fruit influence
Jobs was on a fruitarian diet when he christened Apple. He had just come back from an apple farm and thought the name sounded "fun, spirited and not intimidating."

2 Buddhist beliefs?
He converted to Buddhism after an inspiring trip to India, but was consistently criticised throughout his career for his reluctance to produce environmentally sustainable products.

3 Inner artist
Jobs briefly attended art school, but dropped out after only one term. However, he did put the skills he learned there to use while creating Apple's sleek, well-designed products and gadgets.

4 Control freak
As a perfectionist, Jobs insisted on a 'closed system of control', which meant he had control over each and every aspect of a product from start to finish.

5 Film credits
Jobs bought Graphics Group for $5 million in 1986, renamed it Pixar and changed it into an animation studio. He was later credited as an executive producer on the studio's first full-length film, 1995's *Toy Story*.

1977
The Apple II is a roaring success. Apple Computer, Inc is born.

1985/6
Jobs leaves Apple, founds NeXT and forms Pixar out of a computer-hardware firm.

1996
Returns to Apple as an advisor and steers it away from bankruptcy.

2001
The iPod is launched and becomes the most successful portable music player of all time.

2007
Jobs introduces the iPhone. Shops report shortages within an hour of it going on sale.

2011
Jobs dies of pancreatic cancer, aged 56.

© Rex Features; Corbis; Apple Inc

The Skype Translator

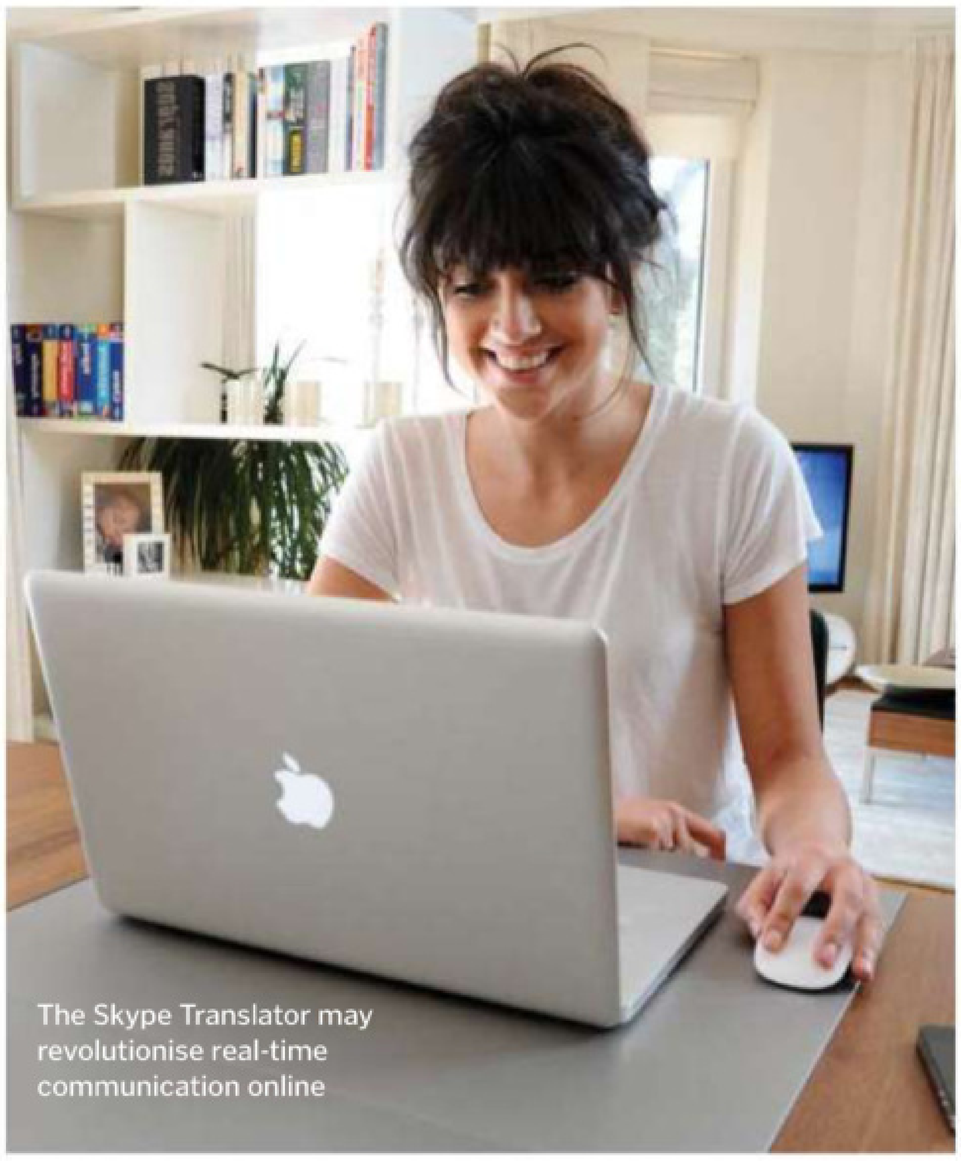
The beginning of the end for language classes?

The immensely popular internet phone and messaging service Skype has approximately 300 million monthly global users. For its next trick, the Microsoft-owned service plans to break down language barriers by automatically translating multilingual voice calls. This bold claim is backed up by some impressive technology.

Using a combination of existing speech recognition, text-to-speech and machine-translation technology, the program will translate any word you utter into a text format of the desired language. Current translation programs use a similar system but can currently only work if they are in the same room. The new Skype software will look to change that, allowing for fully translated international calls.

One stumbling block is the vast amount of different dialects and accents used all over the globe. Because of this, some say there will always be a need for human interpreters as computers can never be completely accurate to detect the really subtle language variations.

The translator is scheduled to be released for the public on Windows 8 by the end of the year, though you can sign up for the Preview version. Other companies such as Lexifone, Google and NTT DoCoMo are working on a similar system. Skype Translator is intended to help in all areas from education to business to international relations. Or maybe just to help you and your German exchange buddy communicate better.



The Skype Translator may revolutionise real-time communication online

How targeted advertising works

How is the internet uncannily accurate at knowing what kind of things we like?

Advertisers use a range of information about you, like your age, gender and location, to flag up relevant ads

If you look at a product on the web you may find that it follows you around, popping up in adverts on seemingly unrelated websites. This is one of the simplest forms of targeted advertising. When you visit a website, third-party advertisers leave tracking cookies in your browser, enabling them to monitor your online activity and remind you later of items or services you looked at earlier.

Search engines like Google collect data about the searches performed from a particular IP address, taking into account search terms, but also the user's location. They even target advertising based on keywords collected from the messages in your email inbox. Your activity on Google-owned sites like YouTube is also fed back to advertisers for use in targeting.

Social networks sell data to advertisers too. Facebook uses the personal information that you provide about your life and interests, along with your 'Likes' and friendships, to help advertisers pitch to a suitable audience.

The computer mouse

How did one little invention help us point and click?

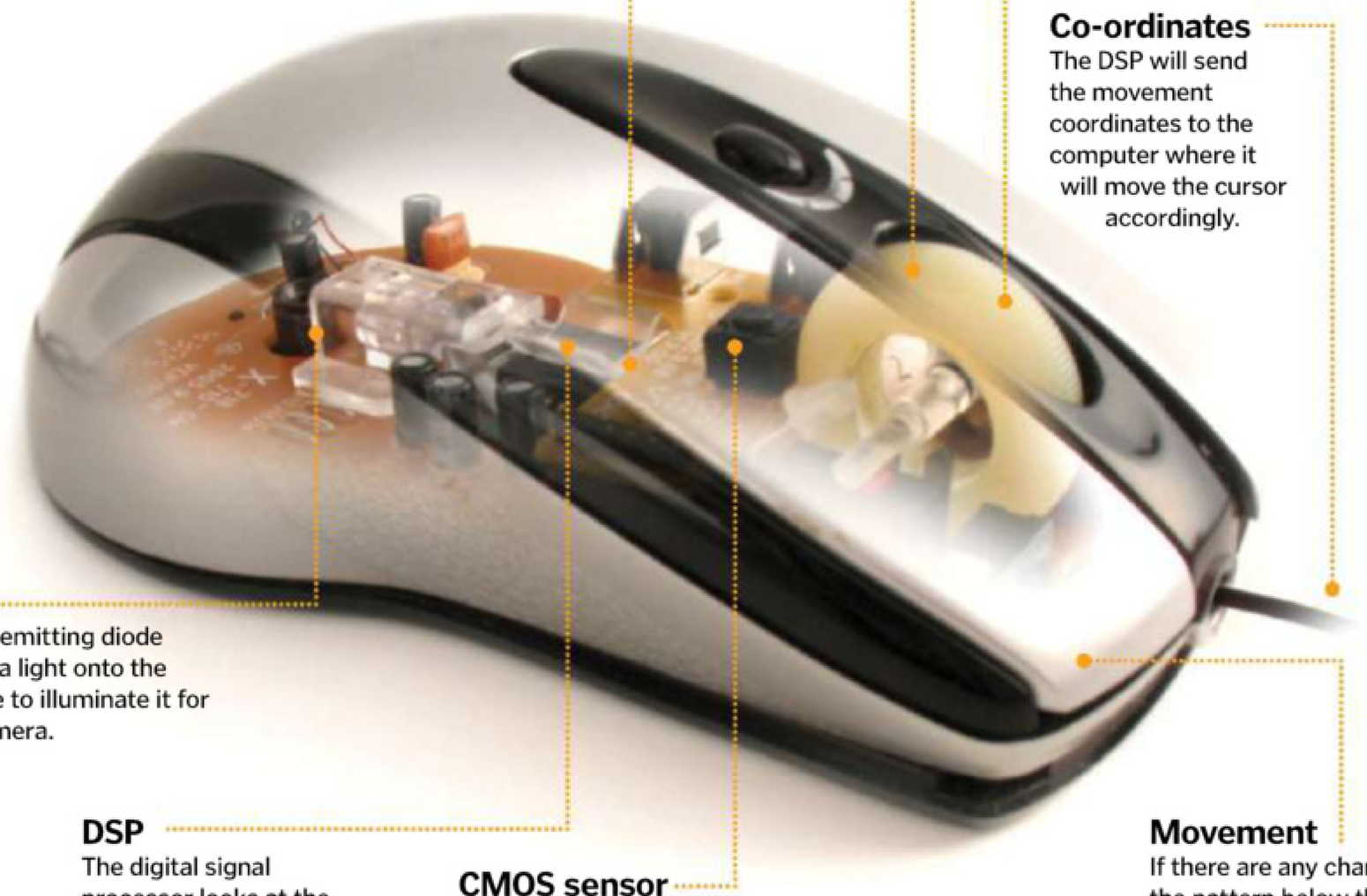
Chances are if you are using a mouse to navigate around your computer that it's an optical mouse. It was invented in 1980 and has pretty much completely replaced the ball-guided mouse. An optical mouse works using microscopic imaging technology. First, a tiny camera inside the mouse photographs your desk or mousemat. The red glow you can see if you turn it upside down is a red light-emitting diode (LED) inside that projects light onto the surface. When the light hits the surface and bounces back into the mouse it hits a complementary metal-oxide semiconductor (CMOS). This sends a message to a digital signal processor (DSP), which closely analyses changes in the pattern of the surface. Once it registers a movement, it sends a signal to the computer, which translates that information into a cursor movement. These adjustments happen hundreds of times every second, so it follows your hand movements in extreme detail.

On top of the mouse is usually either a wheel or a tiny rubber ball. These use the same technology as early ball-guided mice. Rotating the wheel or ball with your finger moves a couple of rollers. These are wired up to a processor which analyses how much each roller has moved and allows you to move a web page or document up and down or, with the ball-topped mouse, side to side.

These developments have greatly helped day-to-day computing, making navigating around the screen much easier than before and revolutionising PC gaming by enabling millimetre-perfect movement.

Inside an optical mouse

What goes on inside your mouse to help you work, rest and play?



Camera
A tiny camera sits in the middle of the mouse, pointing downward and taking 1,500 pictures of the surface below every second.

Wheel
Many mice also feature a wheel on top for additional ease of navigation.

Up and down
This provides vertical movement, meaning you can scroll up and down a web page or document.

Co-ordinates
The DSP will send the movement coordinates to the computer where it will move the cursor accordingly.

LED
A light-emitting diode shines a light onto the surface to illuminate it for the camera.

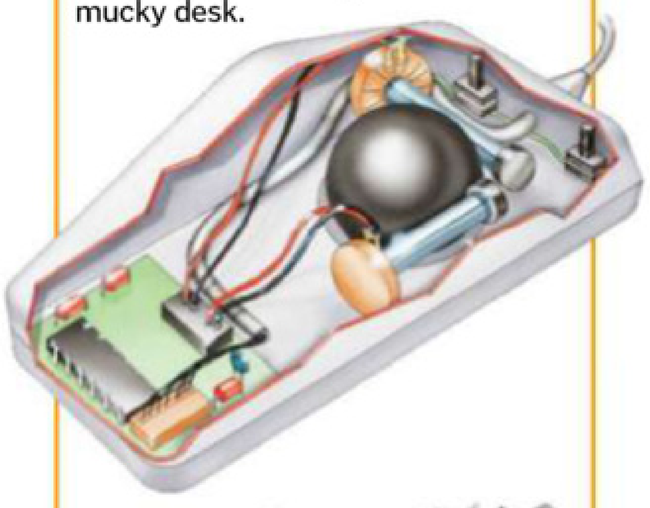
DSP
The digital signal processor looks at the images and notices if there have been any changes in the surface below the mouse.

CMOS sensor
A complementary metal-oxide semiconductor receives the light that has bounced off the surface and sends it for processing.

Movement
If there are any changes in the pattern below the mouse, the sensors will pick that up and work out how much it has moved.

How the roller-ball mouse worked

The roller-ball mouse was the standard design for years before the optical mouse came along, but what went on inside that casing? As you moved your hand around, the ball rolls too. The ball touched two rollers, one behind and one to the side of the ball to detect vertical and horizontal motion respectively. Wires attached the rollers to a circuit board, transmitting movement data. This data was used to move the cursor around the screen with a greater degree of accuracy than the earlier wheeled mouse. The main downside of the roller ball mouse wasn't anything to do with the electronics. Dirt and grime from the surface it was on would collect inside the hole the ball emerged from, making it stick. The new optical mouse does provide a greater degree of accuracy, but its main advantage over the roller ball is that it won't stick if you have a mucky desk.



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How does virtual reality work?

It's been under development for decades, but new technology in the VR field is making CG environments more real than ever

With the 3D craze continuing at your local cinema, what if you could actually immerse yourself in a completely realistic environment and not just have Iron Man flying out the screen towards you? How about going on holiday without leaving your armchair, playing dangerous sports with no risk of injury or taking your videogames to an entirely new level? This has been the promise of virtual reality (VR) since its inception back in the Fifties – and it's starting to be realised with new domestic technology that is within reach of everyone.

Virtual reality isn't like 3D which merely gives the *appearance* of depth on a flat screen; it actually places you within a 360-degree environment that your senses tell you is real.

Remember, what your eyes see or your fingers touch is just electrical impulses interpreted by your brain. VR essentially works by tricking your senses into believing that they are experiencing a real environment when, in fact, it is completely computer generated.

Early virtual world creation applications used VRML (Virtual Reality Modelling Language). This has been superseded by X3D, which uses an XML-based file format. This modelling language can be used with 3D graphics applications, including Blender, which offers a host of 3D rending features for incorporation into VR environments. There are many ways to create VR worlds that can be viewed in a browser, but it's games which have seen the technical advances have been made.

Outside of gaming, virtual reality has many other applications though. The US Army has adopted what it calls its Close Combat Tactical Trainer (CCTT), which uses VR to train soldiers by creating fighting avatars. The system is rather like a cross between the videogame *Call Of Duty* and *Star Trek*'s holodeck.

It's the immersive nature of virtual reality that differentiates it from augmented reality or 3D. Also used by NASA and for advanced surgical training, VR is about to have a renaissance thanks to systems like the Sony HMZ-T2 that offers OLED HD screens, the Sensics zSight and, of course, the Oculus Rift (which we tear down later in this feature).

For VR to work convincingly, you have to feel that you are completely immersed in an

KEY DATES

HISTORY OF VR

1962
Sensorama is one of the earliest fully immersive analogue technologies to offer 3D stereoscopic images.

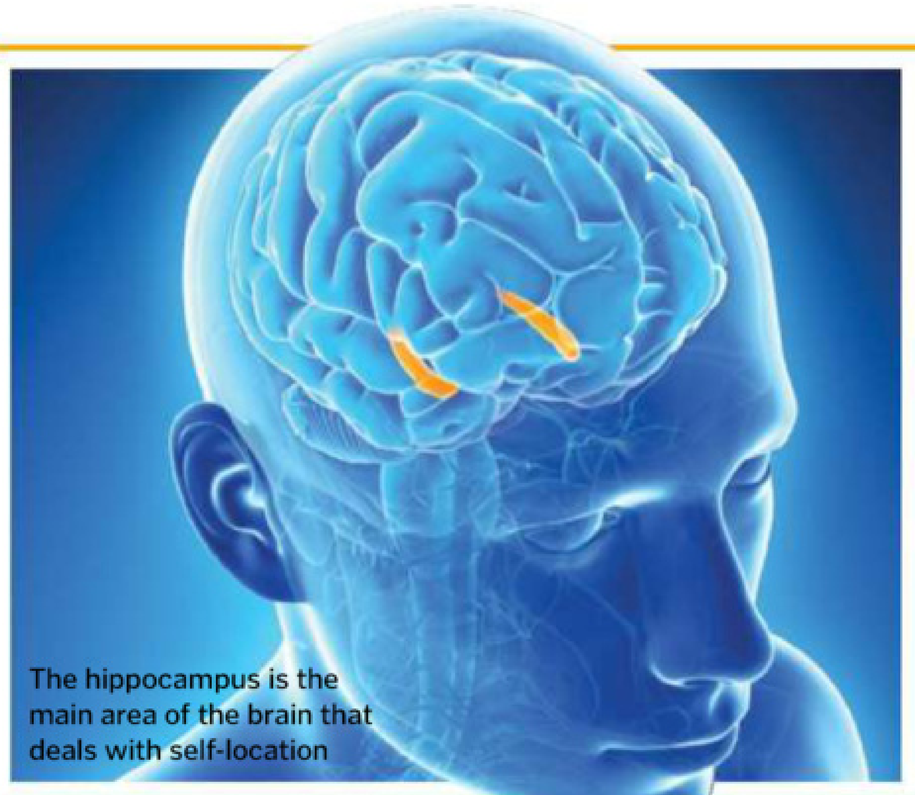
1968
Bob Sproull and Ivan Sutherland use cathode ray tubes in the first head-mounted display.

1986
Thomas Furness develops the 'Super Cockpit' program for the US Air Force.

1987
Computer scientist Jaron Lanier – a pioneer of early VR tech – coins the term 'virtual reality'.

1999
The Matrix is released, and popularises the idea of entering a super-realistic CG environment.

DID YOU KNOW? *A full-body immersion suit for gaming called the PrioVR is currently seeking funding on Kickstarter*



The hippocampus is the main area of the brain that deals with self-location

Tricking the brain

VR works as the brain uses systems including proprioception (the sense of where limbs are in space) and how the eyes orientate to the scene when the head moves. Also, place cells in the hippocampus have been shown to be the centre for self-location, which is used by the brain when assessing where the body is in space.

Ultimately, the brain has to believe the concept of presence, which is based on the brain's past experience of what it feels like to walk down a street, for instance, and how this compares to the virtual street portrayed in the VR environment.

The brain compares these past experiences with the CG environment and decides how real it actually is. Also, when virtual limbs are created in the virtual world, the brain is surprisingly willing to merge the fake with the real. Indeed, in one test VR users pulled their arms away from a virtual fire.

Virtual nausea

Latency is the single biggest barrier to building realistic virtual environments. If the images seen through the HMD are not redrawn (ie rendered) quickly enough, the illusion of reality is shattered. Oculus Rift gets around this issue with what the developers call 'predictive tracking'.

This technology guesses where the user might look next and gets a head-start on rendering the environment. Latency must be minimised at below 50 milliseconds if the brain isn't to detect any lag in the images.

Early VR systems caused motion sickness in some users. This can't be completely cured in some people, but VR systems today have hardware and software that work together to minimise large changes in focus depth or vergence (how eyes focus on an object), which can cause nausea.

Recent developments may combat the motion sickness experienced by some users

environment, but also have the ability to interact with it. It's the interaction – known as telepresence – that sets VR apart from other virtual world systems and 3D cinema. Also, for VR environments to be perceived as real, feedback has to be present.

Think about how you interact with the real world. You can touch and pick up objects, feel their texture and influence things when you open a door or pick up your remote. This is often referred to as force feedback. If you're a gamer, vibrating controllers and body armour that enables you to feel a bullet hit are good examples of force feedback that are collectively called haptic systems. These are essential components of building a realistic VR environment that will fool your brain.

VR systems are often controlled with gaming pads in more advanced systems using VR gloves. Early attempts included Nintendo's Power Glove, with VR systems today favouring a controller approach using platforms such as the Razer Hydra system that is being used extensively with the Oculus Rift head-mounted display (HMD). The Razer Hydra works by using a base station which emits a weak magnetic field. It uses its amplification circuitry, digital signal processor and positioning algorithm to translate the data collected from the controllers into positional and orientation information that in turn is used to control elements of the CG environment which the user is in.

VR uses a number of technologies together to deliver a convincing world to the explorer. The

Key VR hardware

1 Head-mounted display
The most important component of a VR setup. Today's HMDs work via hi-res screen technology. As the eyes are our primary sense, HMDs have to display photorealistic images. The HMD is also packed with motion-tracking devices like accelerometers to place the user in a VR world.

2 Controller
Joysticks, gamepads and gestures are all used to control VR environments. Systems like the Razer Hydra even let you interact with your environment. They work like a remote control to pick up objects and move you around.

3 Body suit
For the ultimate in VR experiences, full body suits have been designed. These contain a number of sensors that detect motion and translate this into the movement of an avatar. Suits can also include hot, cold and vibration points that the computer can adjust.

4 Gloves
Paired with an HMD, VR gloves work by attaching sensors to the fingers. Each sensor detects the movement of each finger and translates this into an action within the world. Reach out with a VR hand and you can pick up an object in the CG environment.

5 Treadmill
A new generation of treadmills designed for VR is emerging. Using special shoes that interact with the treadmill belt you get a much more realistic sense of walking and jumping etc.

HMD is the most important, and uses a technique called stereoscopy that feeds slightly different images to each eye. The Oculus Rift uses a single LCD screen with a colour depth of 24 bits per pixel and includes a 1,000-Hertz adjacent reality tracker that reduces latency to improve the overall quality of the images as the HMD moves. Lenses in front of each eye give the appearance of depth and mean the images totally encompass the wearer's field of vision. With head-mounted displays including tracking software, as the user moves their head, the virtual world moves with them.

A built-in three-axis gyroscope, magnetometers (which measure the strength of the Earth's magnetic field) and accelerometers (to measure how fast the HMD is moving in space) all allow accurate head tracking and therefore the perception that the environment is real. These three technologies change the images fed to the HMD as the wearer moves around. This sense that the scene they see moves as they do is how VR tricks your brain into thinking you are in a real place.

Movement is also a key component of convincing VR. The Omni from Virtuix is the perfect companion for a VR HMD and controller. The treadmill works with the user wearing bespoke pinned shoes. When the shoes make contact with the grooved, low-friction surface of the Omni, the plates within the treadmill move to mimic the walking on a flat surface. Users can even run or jump with their relative position fed back to the computer generating the images shown on the HMD. As users walk unsupported – just as you would in the real world – the illusion of movement through the VR space is assured.

Of course, a computer-generated environment is just that, so how does a VR system ensure you suspend your disbelief and react to the VR world as if it were real? A convincing VR environment must have graphics of a high enough resolution with images fed to the HMD at around 30 frames per second for it to be believable. A precise combination of texture, shading and lighting effects are all needed to generate a lifelike world. Also, sound should be directional and immerse the user in order to make the audio experience equally as convincing.

VR tech has numerous potential applications, notably in combat training

With hi-res images, haptic systems and surround sound, stand on the edge of a virtual cliff and you will feel your heart rate rise – not recommended for anyone with vertigo!

A recent addition to the market was Apple's newest Mac Pro with Intel Xeon E5 Ivy Bridge processors, which has 12 cores. Intel is claiming that this latest generation of chips doubles the CPU performance of its current Xeon range. And with dual AMD FirePro workstation GPUs that can run up to three 4K displays simultaneously, the new Mac Pro is the perfect reality engine for VR exploration.

The Oculus Rift is the latest HMD to attempt to place VR into the hands of everyone, as in the past the prohibitive cost of VR systems meant that only the likes of NASA and the military had deep enough pockets. What Oculus Rift and the rumoured VR HMD for PlayStation 4 could herald is a new age of interactive and immersive experiences. Gaming is clearly the most obvious application, but how about VR on mobile devices? If you have a favourite iPad app, you could add an Oculus Rift HMD for a whole new immersive experience.

If you have often thought that *Star Trek*'s holodeck would offer the ultimate in virtual living, the VR technology that is coming soon could very well offer a taste of what a holodeck might feel like in your very own home.

DID YOU KNOW? *Getting ill in space is no joke, which is why NASA uses VR to test potential astronauts for motion sickness*

Oculus Rift teardown

With affordable HMD tech, a new age of VR exploration is dawning

Lens mounts
Users can choose a number of different lenses to view the screen to ensure a perfect 3D effect is achieved.

HMD
Weighing under 400g (14.1oz), the HMD has a number of components that can be customised to the individual.

Motion tracking
With a 1,000Hz refresh rate, the motion-tracking chips in the HMD ensure smooth scene transitions with very low latency.

LCD screen
A 17.8cm (7in) LCD screen sporting a colour depth of 24 bits per pixel at a resolution of 1,280 x 800px ensures the full field of vision is covered.

Connection interface
The Oculus Rift has a raft of connectors, including HDMI, DVI and miniUSB to ensure HD images from the computer are delivered to the LCD screen with minimal lag.

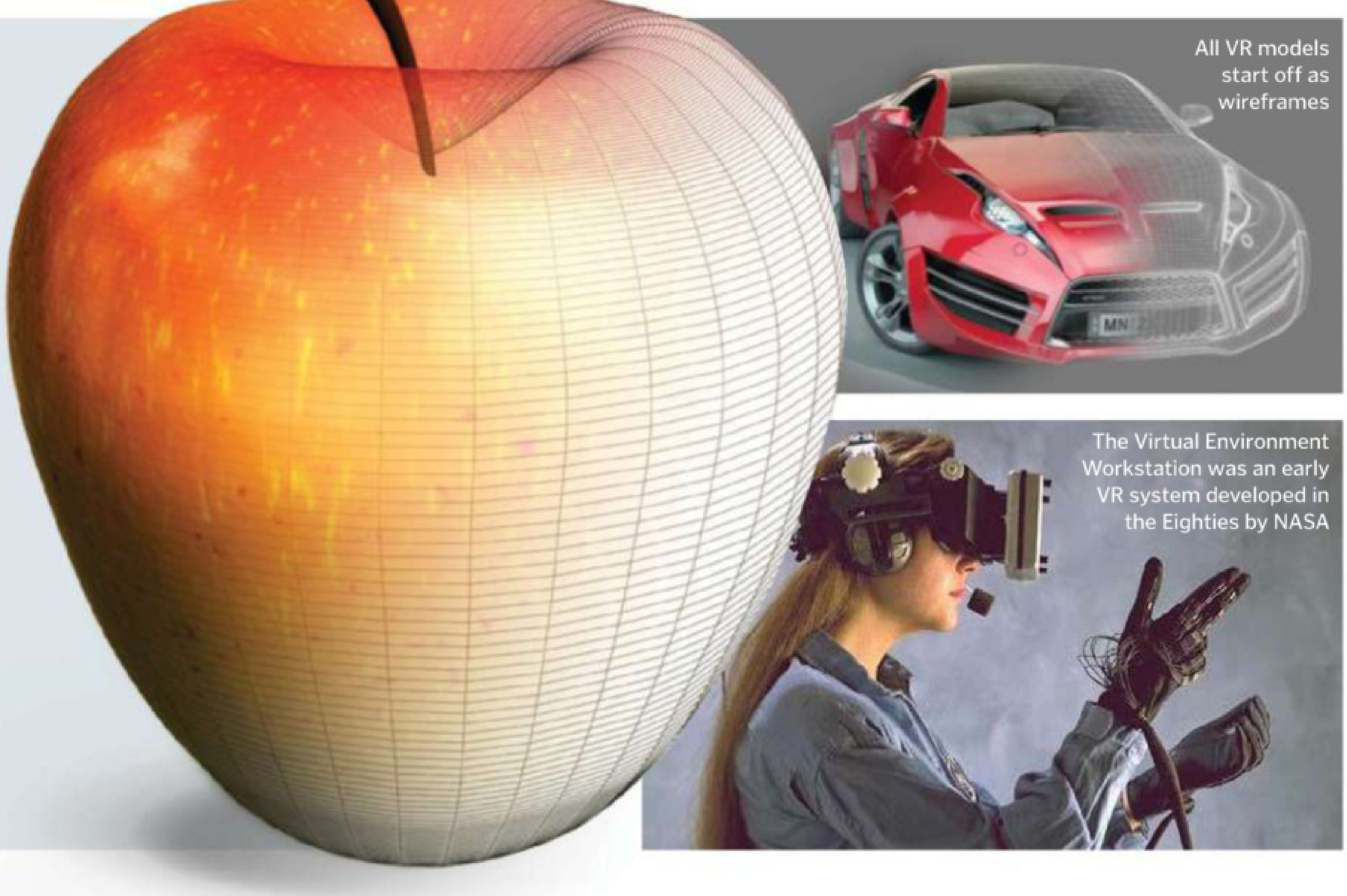
Eyesight correction
Additional lenses can be attached to the HMD to correct any vision differences between each eye.

Designing virtual worlds

There is a plethora of software that can build virtual worlds from commercial offerings, from LightWave, Bryce and modo to open-source applications like Art of Illusion and Blender that can make photorealistic environments, avatars and indeed anything else a virtual world needs.

All these applications use a wireframe, onto which polygons are grafted to create the images needed for a VR environment. 3D graphics applications use colour, reflectance, perspective and texture to render each component of the VR scene.

These applications attempt to duplicate the world around us. This isn't easy, as we know what an apple looks and feels, or how water glistens in sunlight, etc. The skill of the graphics artist and power of the graphics processing of the computers they are using is how VR spaces can seem so real.



All VR models start off as wireframes

The Virtual Environment Workstation was an early VR system developed in the Eighties by NASA

© Alamy; Thinkstock; iFixit.com; NASA; Oculus VR

ENGINEERING

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Inside the world's biggest metropolises

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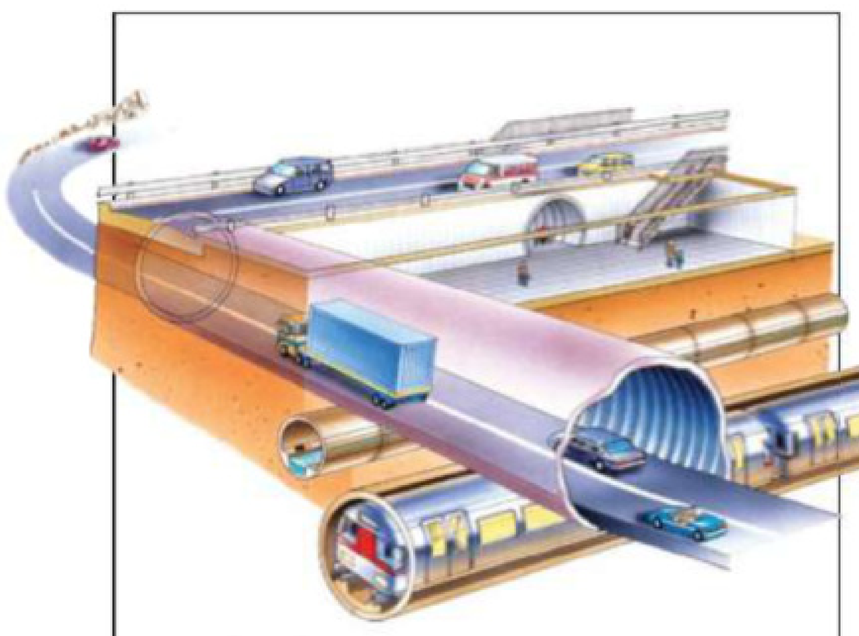

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"In 2000, the 75 largest US cities sat through 3.6 billion hours of traffic jams"

Megacities

The immense engineering technologies that can support massive metropolises

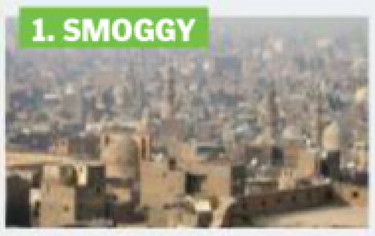
In 1976 when the year 2000 seemed impossibly far into the future, the comic book character Judge Dredd presided over an enormous urban sprawl covering the eastern seaboard of the USA, which was called Mega-City One.

Luckily, that particular dystopian vision of lawlessness never materialised, but megacities themselves are very much real and growing all the time. Solving the many problems that they present is an ongoing challenge for the best of 21st-century technology and engineering minds.

A megacity is one with more than 10 million inhabitants. In 1950, there was only one: New York. Today there are 28 and, by 2025, the UN predicts that figure will have risen to 37. This leap isn't just because the population of the world is increasing; it's because that population is becoming increasingly urban. The majority of today's megacities are in developing countries; their growth is fuelled by huge migrations of the rural poor who are attracted to the megacity by its sheer size and the promise of better opportunities.

London was the largest city in the world during the 19th and early-20th centuries. It was overtaken by New York in 1925 and then in the 1960s by Tokyo, which has held on to the crown since. But ranking the size of a megacity is hard to do accurately, because it depends on how the boundaries are defined. London, for example, grows or shrinks by 6 million people, according to whether you only count the urban population or include the whole of the Greater London Metropolitan Area; the part referred to as the 'City of London' is actually the *smallest* city in England, with just over 7,000 residents!

Jakarta, the capital of Indonesia, has a population of 10 million, which puts it 13th in the world and roughly level with London. But the Jakarta metropolitan area is a sprawling conurbation that has absorbed the cities of Bogor, Depok, Tangerang and Bekasi. This vast complex is sometimes referred to as Jabodetabek, from the first letters of each of the cities. Its total population is over 28



Cairo
A dry climate and unlicensed lead and copper smelting plants have created a thick cloud of smog that appears every autumn.

New Delhi
A combination of road dust and vehicle fumes, as well as pollution from industry, kill an estimated 10,000 people a year in the Indian capital.

Karachi
Pakistan's most populous city, Karachi, is the most polluted megacity, with ten times the air pollution of the world's cleanest megacity, New York.

DID YOU KNOW? *Cities occupy two per cent of the Earth's surface, but consume 75 per cent of its resources*

million – and that's without even including the suburbs – which makes it the second-largest megacity on Earth.

That's still some way behind the 37 million of Tokyo's metropolitan area, but Tokyo's population growth is almost nil today and may even turn negative in the next decade as birth rates in Japan continue to fall. Jakarta, on the other hand, is growing at a rate of more than two per cent per year. Megacities in China and India are growing even faster, and Karachi, Pakistan – which today is fifth in the world – is currently growing faster than any other city has *ever* grown. Indeed, between 1998 and 2011, Karachi more than doubled in size. With growth rates like these, half the world's population could be living in megacities by 2030.

Powering a megacity

London eats 7 million tons of food every year and produces around 20 million tons of rubbish. It uses 28 million tons of concrete, glass and other materials to construct new buildings, and creates 15 million tons of rubble from demolishing old ones. And all of these activities also use electricity and water. The ecological footprint of a megacity extends far beyond the city limits themselves. Tokyo consumes more resources than are produced by all the productive land in the whole of Japan. Indeed, the capital of Japan is only able to function as a megacity because of its ability to plug in to a network that extends overseas and around the globe.

The ability to actively monitor and control that network is crucial to keeping a megacity running smoothly. Mumbai is India's second-largest city, with 19 million inhabitants. Historically it has always had the most reliable power grid in India, thanks to the availability of hydroelectric power. While New Delhi and Calcutta regularly impose rolling power cuts to balance the load on their generating facilities, 95 per cent of Mumbai residents stay plugged in 24 hours a day, 365 days a year. In recent years, however, the megacity has grown to the point where the

2.3 gigawatts that the city power companies can generate isn't enough to meet peak loads of 3.3 gigawatts. To make up the shortfall, power companies buy power in from the surrounding state of Maharashtra, but being connected to the outside grid is risky because sudden spikes in demand around Maharashtra can draw power out of Mumbai and even cause the grid to collapse. In order to prevent this, Mumbai uses a series of sensors that automatically detect when the flow of power into the city changes direction and can trip circuit breakers. These can isolate the city from the state electricity grid and even divide the city itself into 'mini-grids', each served by one of the two main power plants.

Though this may seem selfish, the megacity's isolationist tactic means that the maximum number of customers have their power supply protected and it prevents cascade failures, where excessive demand in one part of the grid causes a domino collapse, as the surplus load is transferred from one network to another.

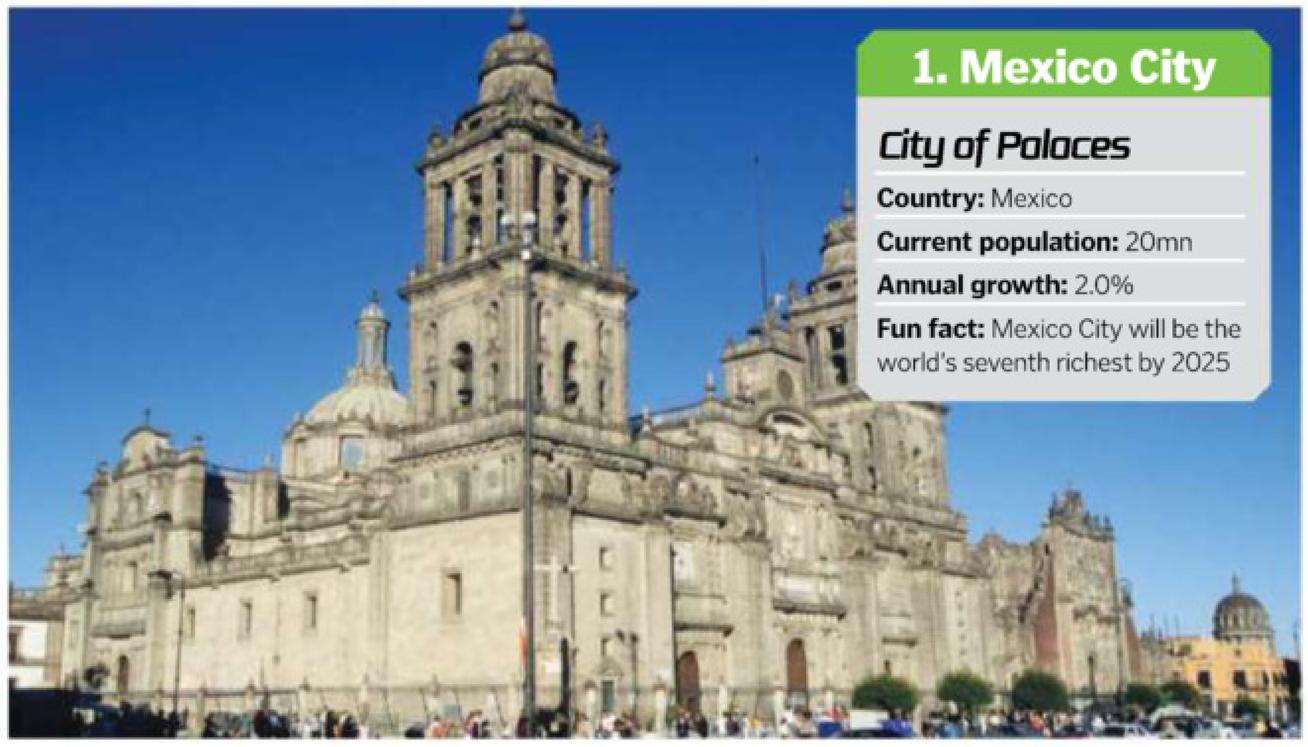
Rapid growth presents an enormous challenge for megacity engineers. In 2011, Hanoi, Vietnam, didn't have a single sewage treatment plant for a population of 7 million people. The drains were all constructed before 1945 and only covered the central part of the old city – about 35 per cent of the present size of Hanoi. As a result the rivers were silting up with black, toxic sludge. Three new sewage treatment plants are currently under construction in a £20 million ($30.5 million) project that is being partly funded by the Belgian government. Between them the facilities will be able to handle 29 cubic metres (1,025 cubic feet) of sewage per second.

One resource that all megacities are short of is space. Utilities need to be routed underground so that they can cover the whole city without strangling it, but keeping track of all the pipes, cables, tunnels and conduits can be extremely difficult when each network is owned by a different group of companies.

In Japan, Geospatial Information Services (GIS) is a new system that maps and monitors all the overlapping layers of the utility grids to enable companies to compare notes and check what lies beneath, before they break out the pneumatic drills and cause any damage. Ironically, the megacity with the longest established and most complex underground network of pipes is New York, however attempts to create a similar GIS map

Ten megacities by the numbers

Source: UN World Urbanization Prospects report, 2011



1. Mexico City

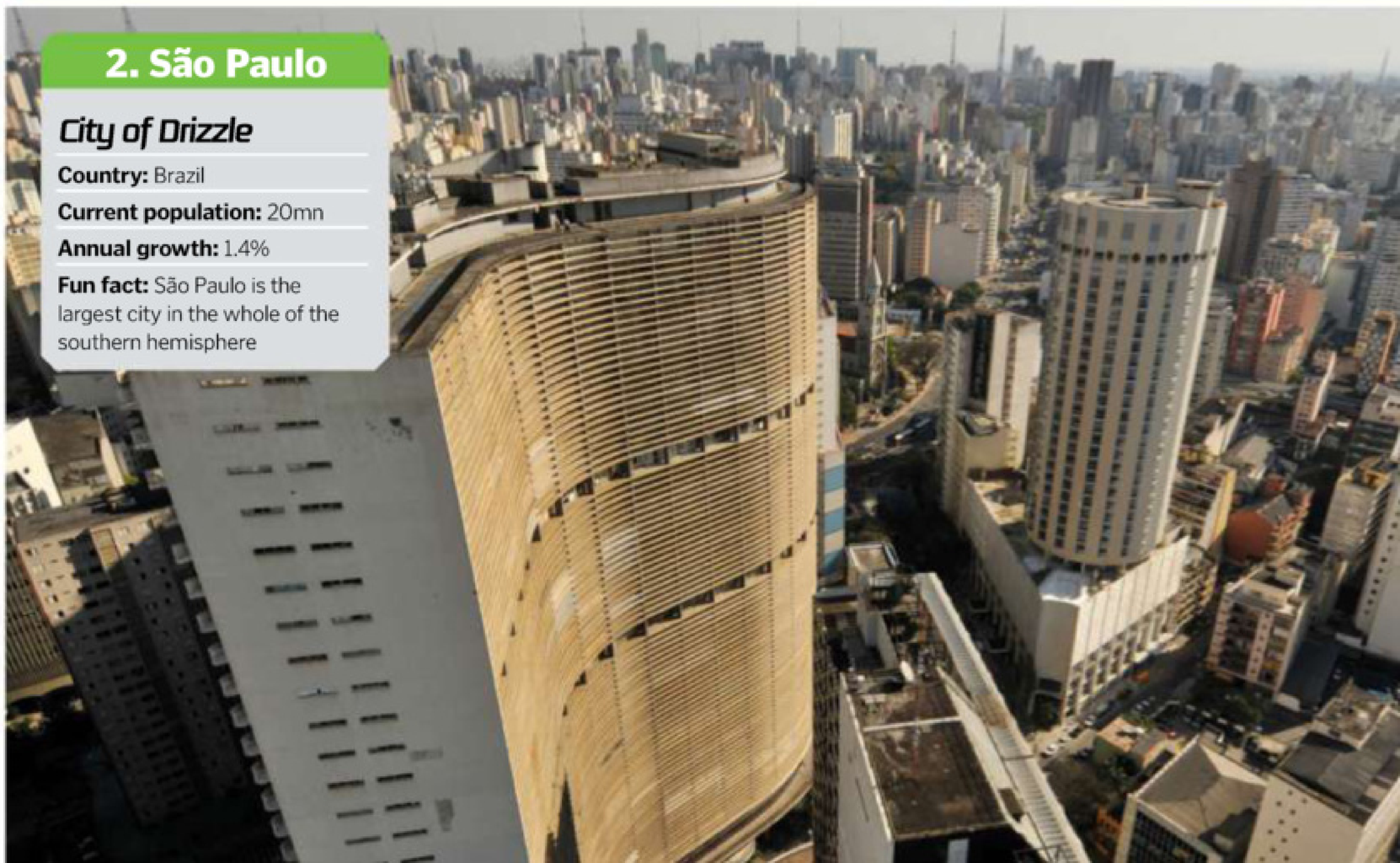
City of Palaces

Country: Mexico

Current population: 20mn

Annual growth: 2.0%

Fun fact: Mexico City will be the world's seventh richest by 2025



2. São Paulo

City of Drizzle

Country: Brazil

Current population: 20mn

Annual growth: 1.4%

Fun fact: São Paulo is the largest city in the whole of the southern hemisphere

DID YOU KNOW? *Jakarta has more Facebook subscribers than any other city: 17 million users and counting*

3. Karachi

City of Lights

Country: Pakistan

Current population: 14mn

Annual growth: 4.9%

Fun fact: The city of Karachi generates 53 per cent of the taxes for all Pakistan

4. New Delhi

Dilli

Country: India

Current population: 22mn

Annual growth: 4.6%

Fun fact: New Delhi households produce approximately 9,000 tons of rubbish per day

5. Mumbai

City of Dreams

Country: India

Current population: 19mn

Annual growth: 2.9%

Fun fact: There are 106,000 auto-rickshaws in Mumbai

8. Shanghai

Paris of the East

Country: China

Current population: 20mn

Annual growth: 2.2%

Fun fact: Almost 40 per cent of Shanghai residents are migrants from rural China

7. Manila

The Pearl of the Orient

Country: Philippines

Current population: 12mn

Annual growth: 2.5%

Fun fact: Manila has the most densely populated city centre of any metropolis on the planet

6. Jakarta

Big Durian

Country: Indonesia

Current population: 10mn

Annual growth: 2.2%

Fun fact: Jakarta is slowly sinking and 40 per cent already lies below sea level

10. Tokyo

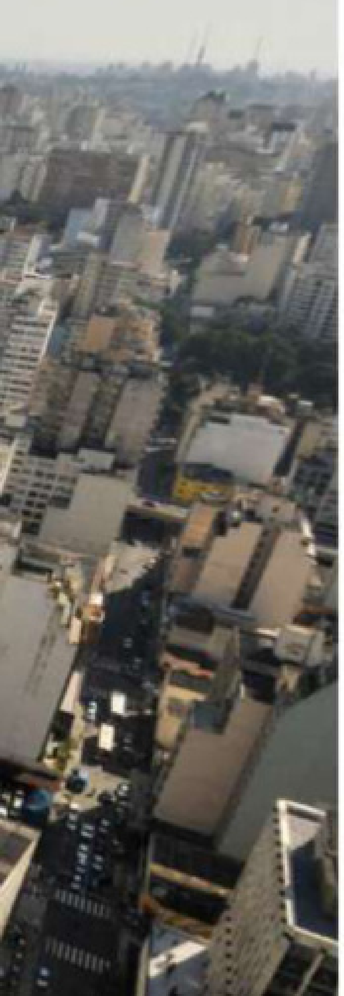
The Eastern Capital

Country: Japan

Current population: 37mn

Annual growth: 0.6%

Fun fact: Tokyo has 23 special wards, each with its own mayor



9. Seoul

Special City

Country: South Korea

Current population: 10mn

Annual growth: 1.4%

Fun fact: Seoul boasts the world's largest cinema screen, sized 31 x 13m (101 x 43ft)

have been stalled by fears that such a system could be exploited by terrorists.

Getting around

We all know megacities are dominated by commuter traffic. To function effectively, a workforce of millions must be transported between the suburbs and the business district at the start and end of every day.

In 2000, the 75 largest cities in the US sat through 3.6 billion vehicle-hours of traffic jams. This wasted 21.6 billion litres (5.7 billion gallons) of fuel and £44 billion ($67.5 billion) in lost productivity. Traffic congestion in typical megacities costs each driver the equivalent of £700 ($1,070) a year in unproductive time. In São Paulo, Brazil, the traffic is so bad that the city has 193 helipads and 420 privately owned helicopters, making it the second-largest helicopter fleet in the world. The largest? That other commuter nightmare, New York.

Since chartering a private helicopter isn't within the budget of most Paulistanos, São Paulo also operates the world's most complex bus system. More than 26,300 buses operate over 1,908 routes with almost 160 kilometres (100 miles) of dedicated lanes. Not only was the city one of the first to pioneer microchip-based cashless payment systems much like London's Oyster card, but it has gone much further, with computer-controlled route scheduling packing buses more efficiently into the bus lanes. A typical lane on a motorway or freeway can transport no more than 2,200 car passengers an hour. In contrast, São Paulo's Bus Rapid Transit (BRT) network manages 15,000 an hour. This is on a par with most light rail systems, but without the enormous additional cost and extra space required for building tracks.

Even more efficient, however, are subway systems. Underground train lines can connect stations in straight lines without routing around buildings or following historical road layouts – and multiple train lines can be dug at different levels, so that they overlap without the need for signalling. Underground trains can be stacked much closer together than surface trains and they don't suffer from leaves on the line or the 'wrong type of snow'.

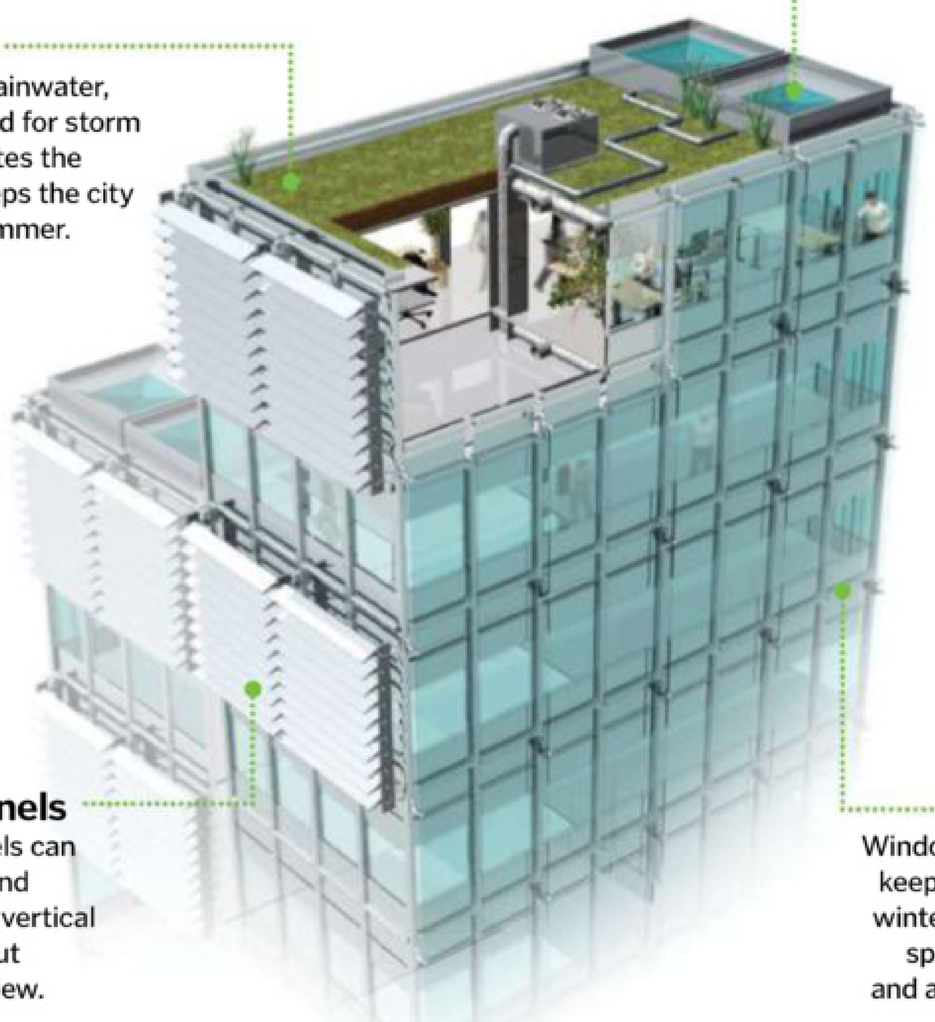
Though London has the oldest subterranean train network in the world – and one of the largest in terms of track miles and stations – it is completely dwarfed by Tokyo's Metro. Trains are the primary mode of transport in Tokyo and it has 882 separate

Sustainable office space

In an effort not to strangle a city under the weight of its own infrastructure, urban planners around the world are exploring ways to make buildings self-sustaining. The Hearst Tower in New York, for instance, was built using a diagonal grid ('diagrid') that uses fewer steel beams than a traditional cuboid shape and 80 per cent of that steel is recycled. In Chicago, the 340 On The Park development uses a rainwater-capture system to irrigate a multistorey winter garden on the 25th floor. While in Rotterdam, Holland, Urban Cactus takes this a step further with a staggered system of curved balconies, giving each apartment a private garden that receives lots of sunlight. Helical wind turbines can also be mounted on the top of a skyscraper or run down the sides. Indeed, the Waugh Thistleton tower in London will generate up to 15 per cent of the building's power needs this way.

Learn more

To find out more about the future of sustainability we recommend you pay a visit to the British Science Festival. In 2015, the event is taking place in Bradford from 7 - 10 September where – as usual – you'll be treated to a packed programme of events. This includes shows, talks and street science on everything from the history of fossil fuels to how we'll feed the world in 2050. For details head to **www.britishscience association.org**.



Green roof
Grass absorbs rainwater, reduces the need for storm drainage, insulates the building and keeps the city cooler in the summer.

Roof pond
Rainwater can be used to supply some of the building's needs, instead of draining away to the sewers.

Louvred panels
Adjustable panels can generate heat and electricity from vertical surfaces, without obscuring the view.

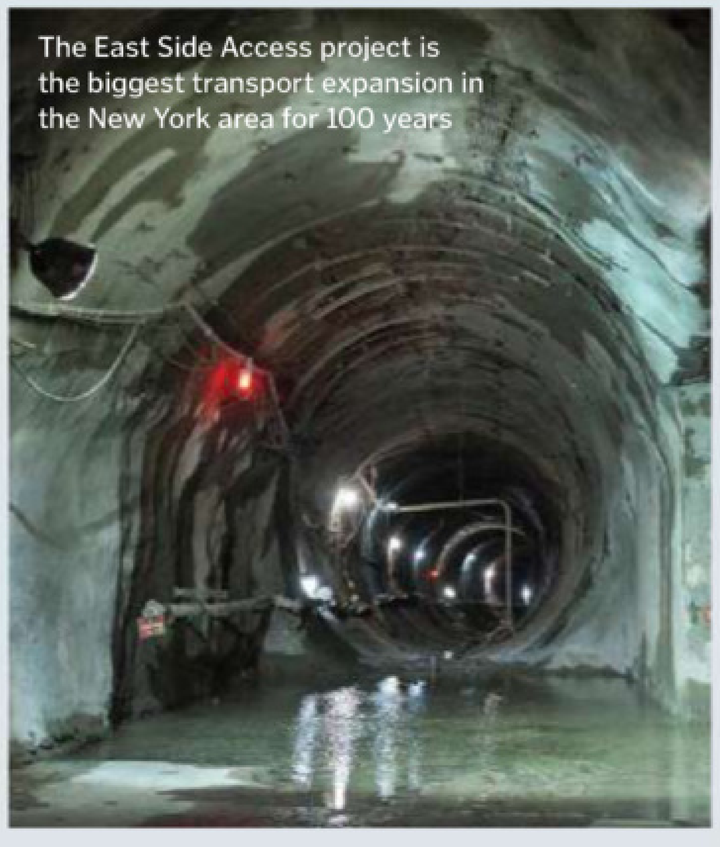
Smart glass
Windows use coatings that keep the building warm in winter and cool during hot spells, reducing heating and air-conditioning costs.

Getting into New York

The Long Island Rail Road (LIRR) carries 81 million commuters a year between Long Island and Manhattan. It is the second-busiest commuter line in North America and the only one to run 24/7. The East Side Access project is designed to extend the rail line farther into the centre of Manhattan, so that it connects directly to Grand Central Station.

The $8.8 billion (£5.8 billion) scheme is being built entirely underground, with a terminal at Grand Central, a whole new station in Queens and eight new station tunnels. These were excavated by two 580-ton tunnel-boring machines, digging 43 metres (120 feet) below street level.

This mammoth project was originally due to be finished by 2013, but this has now been pushed to August 2019. When it does open, the extra 162,000 commuter journeys made each weekday will also increase pressure on connecting train and bus links. Other schemes, such as the $17 billion (£11 billion) Second Avenue Subway project – also long overdue – will be needed to cope with the load.



The East Side Access project is the biggest transport expansion in the New York area for 100 years

KEY DATES

URBAN SPRAWL

150 CE

At the height of its empire, the city of Ancient Rome has a population of 1 million.

1800

Just three per cent of the world's population – around 30 million people – live in cities.

1962

Tokyo overtakes NYC as the largest city in the world. It has remained at the top ever since.

2013

There are now 28 megacities in the world; 18 are in Asia and just four in Europe.

2025

Kinshasa, Shenzhen, Guangzhou, Bogotá, Lima and Lahore are all expected to reach megacity status.

DID YOU KNOW? *City residents in the USA use 450l (119ga) of water a day each; African megacities use 100l (26ga) per person*

What lies beneath?

The foundations of a city do a lot more than support its weight. A tangled maze of pipes, tunnels and cables runs under every street and pavement. Burying them keeps us safe from gas, electricity and sewage, and protects delicate data cables from damage.

Water
Pressurised water, fed by a pumping station to a series of water towers or reservoirs, connects every office and residential building.

Electricity
Electric cables usually run in shallow conduits under the pavement.

Steam
A few cities – most notably New York – have a pressurised steam network to supply power and heating to office blocks and apartments.

Sewage
Sewer pipes double as emergency storm drains and are much wider and deeper than any other services.

Gas
Gas pipes are buried deeper than electrical cables – to reduce the risk of accidental rupture and explosion.

Phone, internet and television
Data cables often share pipes or conduits with other services to minimise the amount of digging needed.

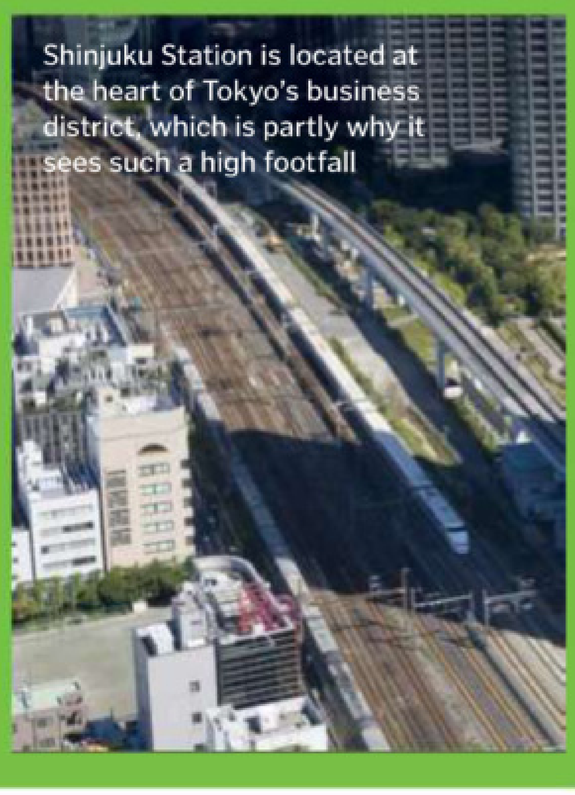
Abandoned
It's often cheaper to run new services in their own trench, rather than digging up an old section of pipe.

The busiest train station in the world

Tokyo's Shinjuku Station isn't just the busiest rail station in the world – it's the busiest transport hub of any kind. Over 1.2 billion people pass through it every year: the equivalent of the population of Japan ten times over. London's busiest station, Waterloo, handles less than one-13th as much traffic.

Shinjuku has 36 separate platforms serving ten different train operators running on six train lines that converge on the station. It actually functions as a cluster of five different stations, each managed by a different company. This includes two separate subway systems – one of which, Tokyo Metro, is also the busiest subway on the planet.

To keep over 3.5 million passengers a day flowing smoothly through the Shinjuku Station complex, the overground trains have platforms on both sides of the track, with one for passengers getting on and one for those disembarking the train. Platforms are connected by a series of concourses on several different levels. The Odakyu Station section of Shinjuku, for example, covers ten platforms across two levels beneath the Odakyu department store. Six of these are at ground level and four are underground. Altogether, Shinjuku Station has 200 exits to street level.



Shinjuku Station is located at the heart of Tokyo's business district, which is partly why it sees such a high footfall

Dealing with disasters

The streets and subways of any megacity can only just cope with the normal levels of traffic in rush hour. A natural disaster or terrorist attack can instantly overwhelm available escape routes and crash mobile phone networks.

But the more notice residents have of a disaster, the less chaos ensues. In Japan a network of 1,000 monitoring stations can detect earthquakes and signal major cities a few tens of seconds before they hit. That's enough for sensors fitted in every single lift to automatically stop them at the nearest floor, and slow down all trains to a safer speed. Some Tokyo apartments even have special alarms that count down to a quake. Phone networks often crash or slow down after a terrorist attack due to the sudden spike in calls. The rise of Twitter has provided a useful way to reassure family and Google has also begun trialling its Person Finder (**www.google.org/personfinder**) service to help reconnect people after disasters.

stations with 30 train operators running on 121 train lines; that's one station for every 4.1 square kilometres (1.6 square miles). Every day 40 million passengers board Tokyo's trains and, at rush hour, the trains are so crowded that railway staff called oshiya (which translates as 'pushers') physically shove commuters on to the trains so that the doors are able to close. Though it looks pretty brutal to outsiders, this allows trains to leave much more punctually; the Tokaido Shinkansen 'bullet train' arrives at JR Central Station in Tokyo within six seconds of its scheduled time, on average.

Another key advantage of underground trains is that they can run on electricity, which reduces the amount of air pollution. New York is the megacity with the cleanest air, in part because of its subway, while Karachi in Pakistan, which is the most polluted megacity, has no mass transit system at all.

Traffic pollution isn't just about fumes and smog though. Noise pollution is a significant problem in many megacities. Electric vehicles do a lot to reduce this, but interestingly there is a psychological element as well. Research in Munich in 2005 showed that, for exactly the same decibel level of noise, we perceive a red train to be louder than a green one. Trains in Germany are often red or have a red stripe, whereas Japanese train companies favour white trains with a green or blue stripe.

Technology boom

Global population is expected to stabilise at 10 billion, but *urban* populations could keep rising. As countries become more developed, their cities swell. Boundaries burst and conurbations merge to form megacities. In southern China, for example, nine cities in the Pearl River Delta are being joined up to create a single metropolis of 42 million people that will be 26 times larger than Greater London and twice the size of Wales! Stitching these cities together involves 150 infrastructure projects to link energy, telecommunications, water and transport networks. Together they will cost £190 billion ($289 billion), but the resulting megacity is expected to account for more than ten per cent of China's GDP.

Megacities can provide the reactor core for a nation's economy, but scaling them up isn't just a case of building more skyscrapers. Once it reaches critical mass, a megacity can go into meltdown without the technology to support its population, as we explore on this page.

Technology to the rescue!

Ten technologies that megacities will take advantage of in the future

Commuter power

A rushing commuter gives off about 100 watts of heat. That energy is normally just wasted, but with heat exchanger technology it can be channelled to a nearby building. Rambuteau Metro Station in Paris channels the hot air from the morning rush hour through pipes to heat 17 apartments in the building next door. Stockholm Central Station in Sweden uses the same technique to heat a nearby office block.

Driverless cars

Free Ranging On Grid (FROG) technology uses vehicles with a built-in map of a defined area. Passengers call a FROG car from a pickup point, just like calling a lift, and select their destination from a touchscreen map. FROG vehicles are already used for cargo loading in some ports. By combining this technology with GPS navigation from Google, driverless cars could offer much tighter traffic spacing and better use of the road network.

Biogas buses

Biogas can be produced by using bacteria to digest almost any organic matter. This includes waste food from restaurants and sewage. Even a megacity doesn't generate enough waste to power all of the cars on the road, but it could run the public transport system. Linköping has a fleet of biogas buses and the world's first biogas commuter train too.

Gigabit internet

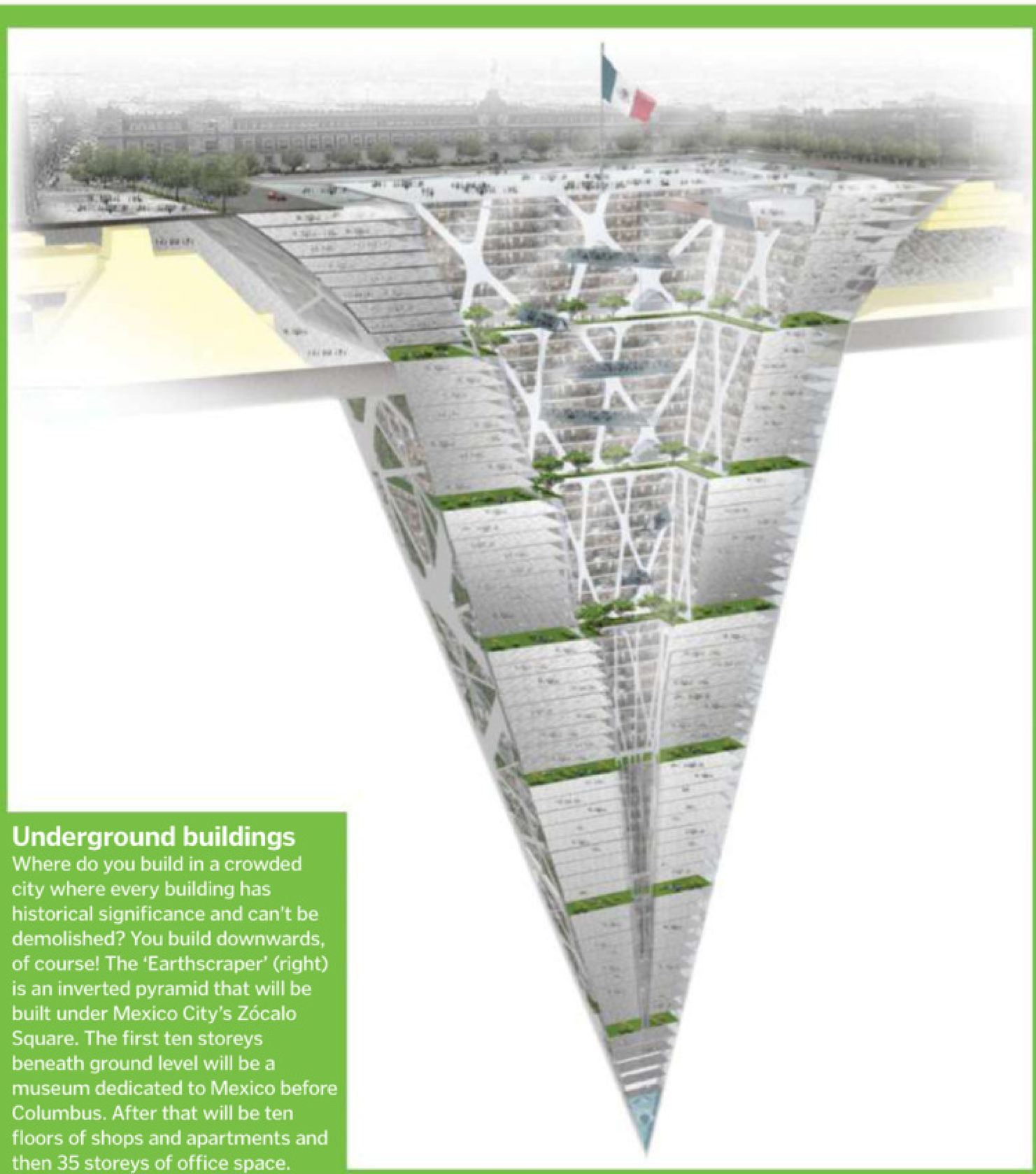
Last year Google began trialling its Google Fiber service. This offers 1,000 megabits per second for both upload and download of data – roughly 100 times faster than most broadband speeds. More bandwidth makes working from home easier using cloud computing, and this reduces the transport demands on the inner city. Austin, TX, and Provo, UT, also signed up to the Fiber service this year.

293km

WORST-EVER TRAFFIC

São Paulo in Brazil broke the record for the worst rush-hour jams in 2009. On 10 June, 293 kilometres (182 miles) out of the city's 888 kilometres (552 miles) of road were gridlocked.

DID YOU KNOW? *New York City has 34,000 police officers, costing $4.6bn (£3bn) each year*



Underground buildings

Where do you build in a crowded city where every building has historical significance and can't be demolished? You build downwards, of course! The 'Earthscraper' (right) is an inverted pyramid that will be built under Mexico City's Zócalo Square. The first ten storeys beneath ground level will be a museum dedicated to Mexico before Columbus. After that will be ten floors of shops and apartments and then 35 storeys of office space.

Mega-skyscrapers

US architect Frank Lloyd Wright first proposed a mile-high skyscraper in 1956. The compressive strength of the best concrete then would only allow for a 20-storey building, but new concrete formulations with carbon nanotube fibres could be ten times stronger. Saudi Prince Al-Waleed bin Talal has spoken of plans for a mile-high skyscraper. Currently, the Kingdom Tower in Jeddah, designed by Adrian Smith and Gordon Gill, will be Earth's tallest building come 2017 at 1km (0.6mi) high.

Artificial trees

Parkland is an important part of any city, but the amount of carbon dioxide the trees planted there can remove from the air is fairly small. Artificial 'trees' that are specifically designed for the task can remove CO_2 approximately 1,000 times faster than a similar-sized tree. Plus algae-filled, photosynthetic pipes can be run down the sides of skyscrapers to suck carbon from the city pollution.

Next-gen bullet trains

Japan's bullet trains already manage an average speed of 240km/h (150mph), but the new-and-improved L01 uses superconductive magnetic levitation (maglev) technology to float above the tracks and electromagnetic propulsion systems to rocket along at almost 500km/h (310mph). This will cut the commute times between Tokyo and the city of Nagoya in the neighbouring Chubu prefecture from 90 minutes to just 40. The ultra-streamlined train is scheduled for track tests in September 2013 and will begin operation in 2027.

Pay-as-you-throw refuse

Instead of charging a fixed price for rubbish collection as part of local rates, pay-as-you-throw (PAYT) automatically 'meters' the service using different-sized bins. Radio-frequency (RFID) tags on certain recyclable containers charge residents more if they throw away materials that could have been recycled. This reduces the total amount of rubbish chucked away and also creates consumer pressure to do away with unnecessary packaging.

Civic responsibility apps

Code for America has been described as 'a Peace Corps for geeks'. It is a non-profit organisation that uses smartphones and social media to encourage civic engagement. In Boston, MA, for example, users can sign up to 'adopt' a fire hydrant near their home and commit to keep it clear after heavy snowfalls.

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The Empire State Building

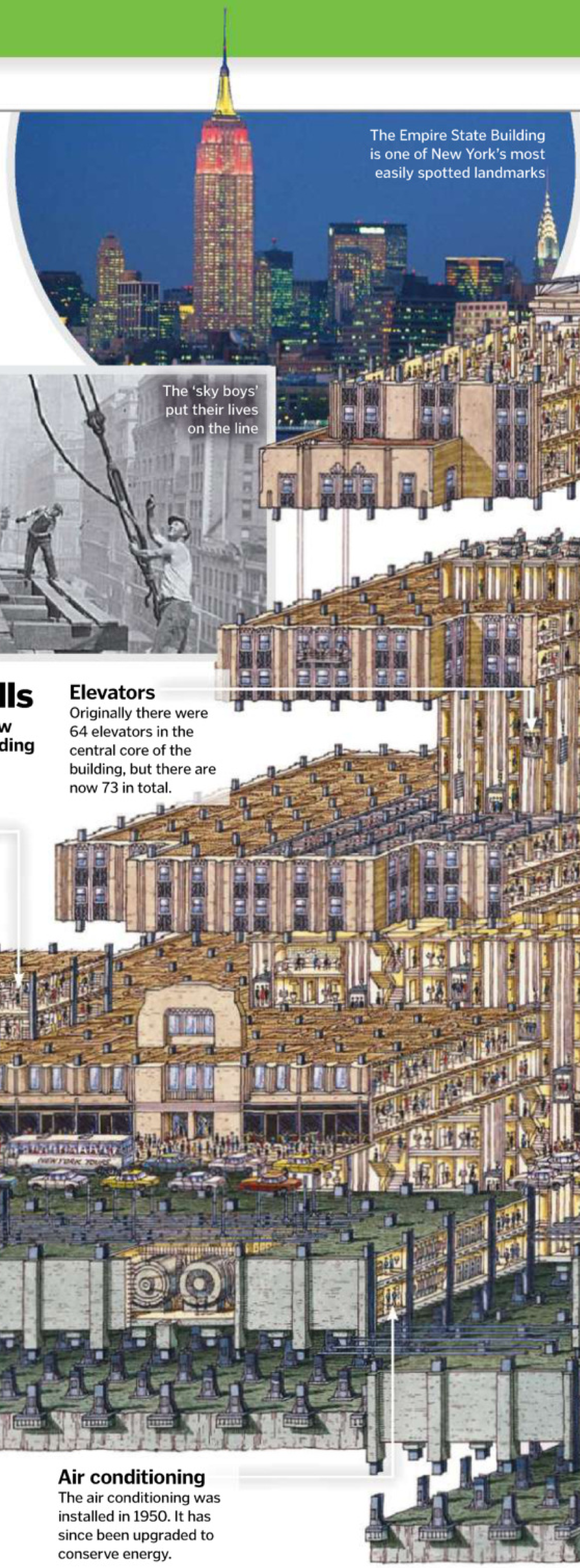
How this US icon came to tower over New York City

With 103 floors and a 56-metre (185-foot) spire, the Empire State Building is an incredible 443.2 metres (1,454 feet) high. The world's tallest skyscraper when it was opened on 1 May 1931, it pipped New York's beautiful 319-metre (1,046-foot) Chrysler Building to the record and held onto it until 1970, when New York City saw the World Trade Centre spring from the pavement. They certainly build them big in the Big Apple and for 40 years, the Empire State Building was the biggest of them all.

The invention of steel framing in the late-19th century had made it possible for buildings to be taller than ever. While brick would eventually collapse under its own weight if you piled on too many floors, a honeycomb-like frame of steel beams could take the strain and spread the pressure of the upper floors throughout the building. Another 19th-century development – the elevator – raised the limit on how many storeys you could put on a building, for the simple reason that you can't expect someone to walk up 102 flights of stairs.

Construction began in March 1930. Financed by two former General Motors executives, John J Raskob and Pierre S du Pont, they applied the same revolutionary style of working that they'd used in the factory, with assembly lines of men putting the building together in shifts. However, without the benefit of modern cranes and lifting equipment, materials were hoisted up by pulleys and moved around the inside of the building on narrow railway tracks.

As many as 3,500 workers were on the building at once, many of them (known as 'sky boys') balancing on beams high above the city with no harnesses or helmets. It would be considered incredibly dangerous and reckless today, but those conditions were accepted as part of the job in 1930. After all, only five people died in the 410 days of its construction...



The Empire State Building is one of New York's most easily spotted landmarks

The 'sky boys' put their lives on the line

Behind the walls

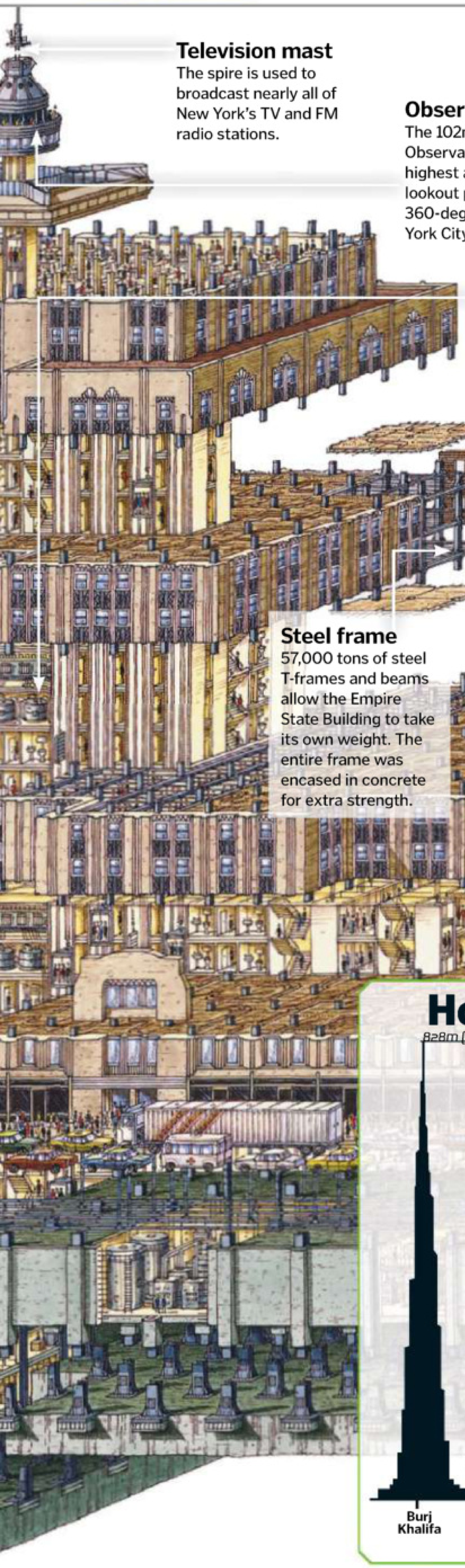
Everything you need to know about the Empire State Building

Elevators
Originally there were 64 elevators in the central core of the building, but there are now 73 in total.

Office space
With 1,000 businesses based there, the Empire State Building is the second-largest office space in the US after the Pentagon.

Foundations
The Empire State Building's concrete foundations extend 16.7m (55ft) below ground.

Air conditioning
The air conditioning was installed in 1950. It has since been upgraded to conserve energy.



Television mast
The spire is used to broadcast nearly all of New York's TV and FM radio stations.

Observation deck
The 102nd Floor Observation Deck is the highest and smallest lookout point, offering 360-degree views of New York City.

Water supply
While most buildings store water on their roof, the Empire State Building has water tanks spread throughout and connected by 113km (70mi) of pipe.

Steel frame
57,000 tons of steel T-frames and beams allow the Empire State Building to take its own weight. The entire frame was encased in concrete for extra strength.

Limestone panels
The outside of the skyscraper is covered in panels of Indiana Limestone, behind them are 10 million bricks.

Windows
Did you know there are 6,500 windows in the Empire State Building? That's a lot of cleaning!

Entrance
The main entrance has a 9.1m (30ft) high frontage with diamond-shaped frames of glass and two carved eagles on pillars.

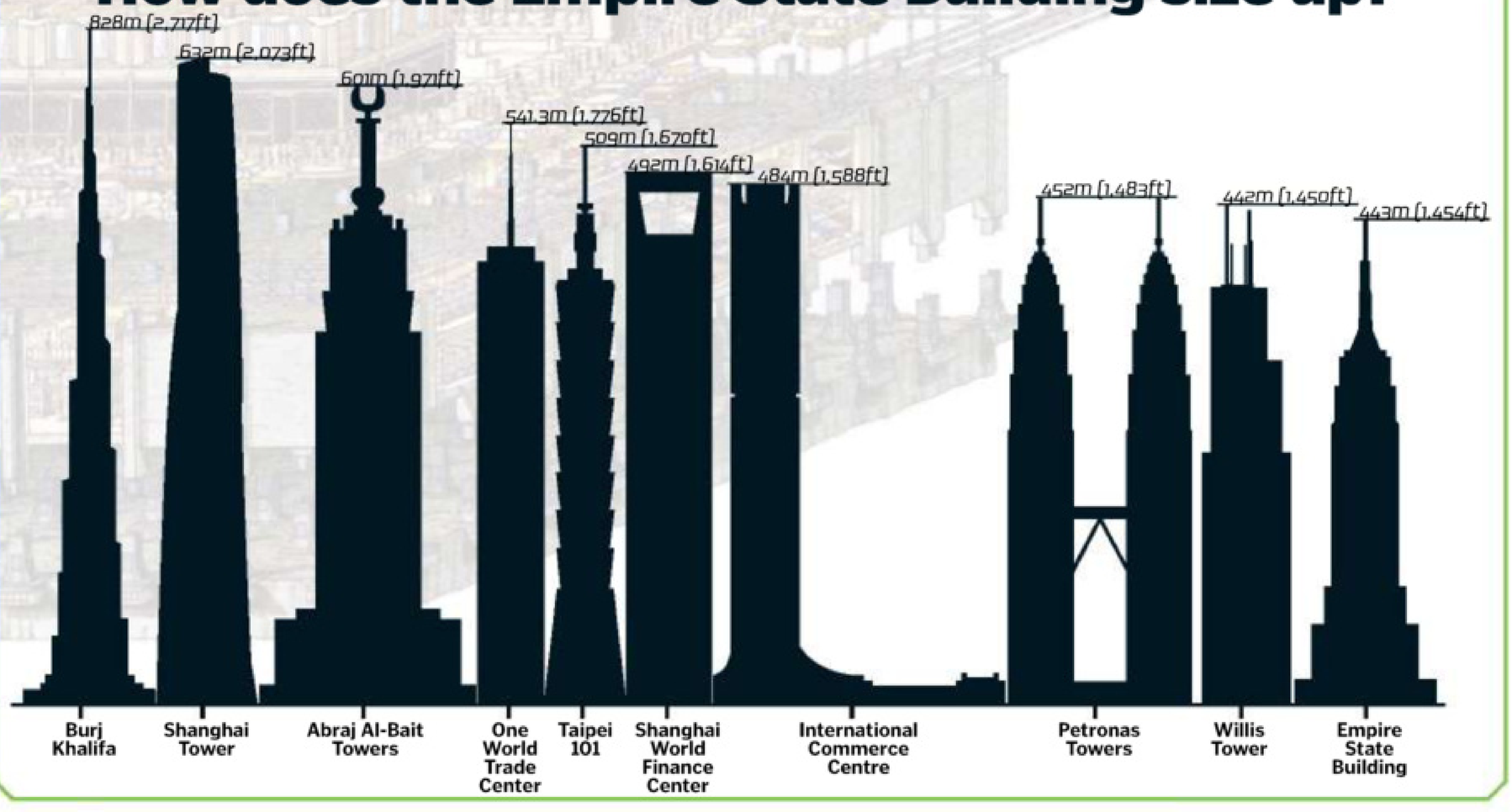
Beautiful shapes

Although not as stylish as the Chrysler Building, the Empire State is an example of the architectural style known as Art Deco. Prominent in the 1920s, '30s and '40s, Art Deco is recognised by its bold geometric shapes, symmetrical design and ornate decorations.

The Empire State Building's most prominent Art Deco features are the 'setbacks', where levels of the building become narrower the higher it goes, with overlaps between the small parts and larger parts. Because they look like steps, they're also called 'stepbacks' and give the Empire State its instantly recognisable shape. Angular sculptures can be found over the entrances, but its inside was where the decorations were at their most impressive with a gold-leaf mural on the lobby ceiling, marble walls and floors, and Art Deco chandeliers.

The Empire State Building is the world's most famous Art Deco building

How does the Empire State Building size up?



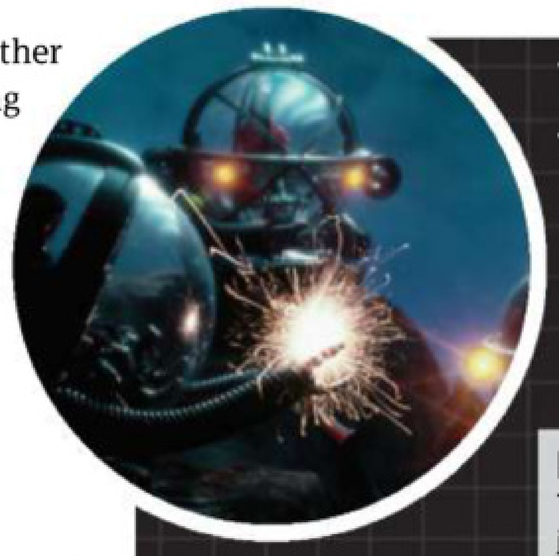
© Thinkstock; DK Images

How do we weld underwater?

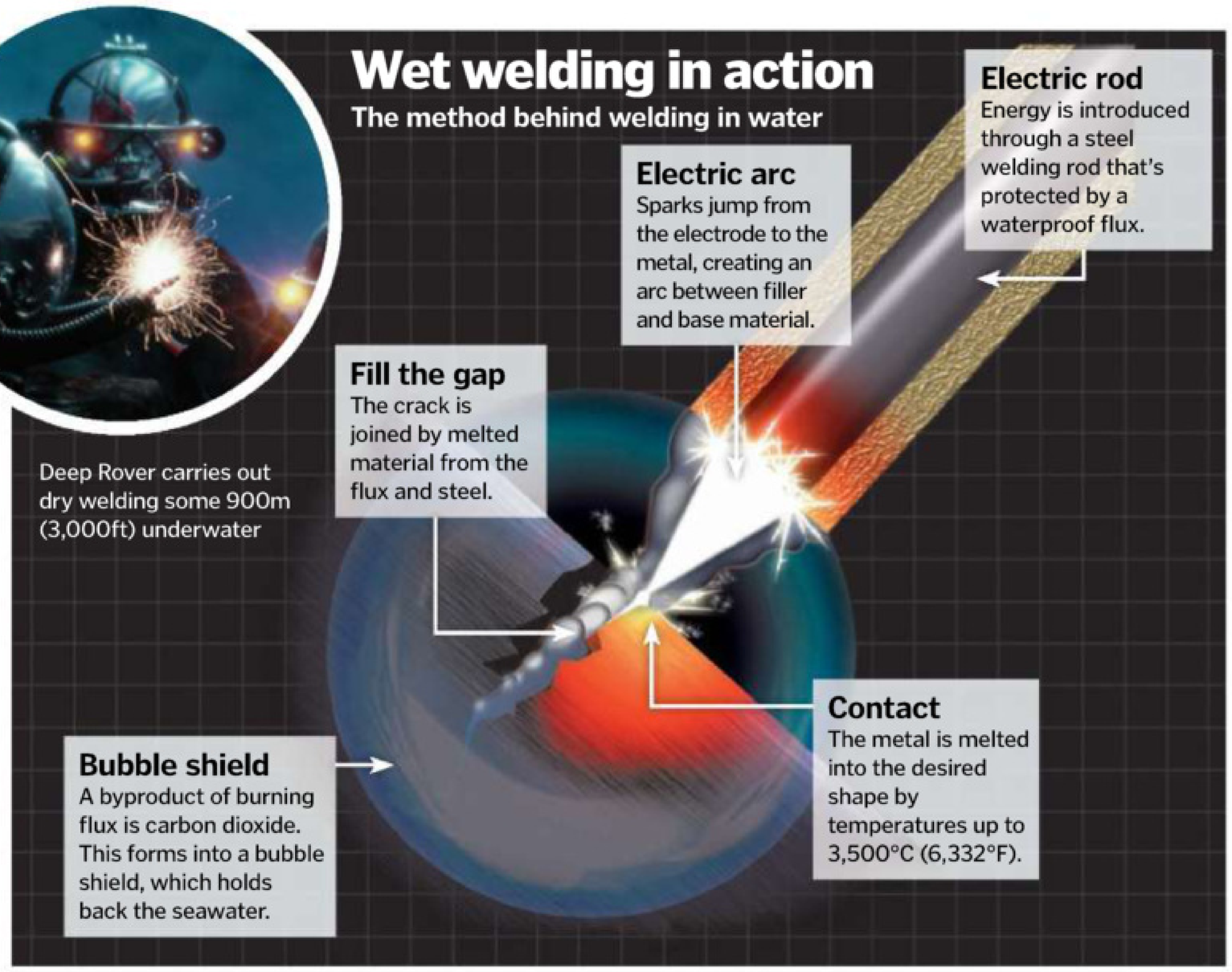
Find out how we patch up holes in vessels and pipes in a watery environment

Joining and fusing materials together has been a key part of engineering for centuries, but what about doing it underwater? High-pressure welding, more formally called hyperbaric fabrication, can now be undertaken in water in two ways.

Dry welding is done in a closed chamber, while wet welding can join metals completely exposed to water. An example of a dry welder is the Deep Rover submersible. Primarily used for exploration, this vehicle can hold up to two people in a sealed sphere and is capable of lifting chunks of metal too. Wet welding, on the other hand, creates a bubble of carbon dioxide around the weld point while the repair is made. Dry welding is safer due to the added protection but tends to be more expensive and time-consuming. Therefore, dry is better for larger, more involved projects while wet is generally used for smaller tasks. Both are used primarily to repair marine structures and deep-sea pipelines and can also be carried out by robots. Welding temperatures can reach 3,500 degrees Celsius (6,330 degrees Fahrenheit).



Deep Rover carries out dry welding some 900m (3,000ft) underwater



What are jumping mines?

Discover how delay charges enable mines to detonate in the air

Bounding mines, like the German 'Bouncing Betty' and the US M16, differ from other anti-personnel mines as they explode in mid-air. When the fuse is activated, a propelling charge is fired, launching the mine out of the ground and, after a short delay, the main charge is detonated, showering its vicinity with shrapnel.

Inside an M16 mine

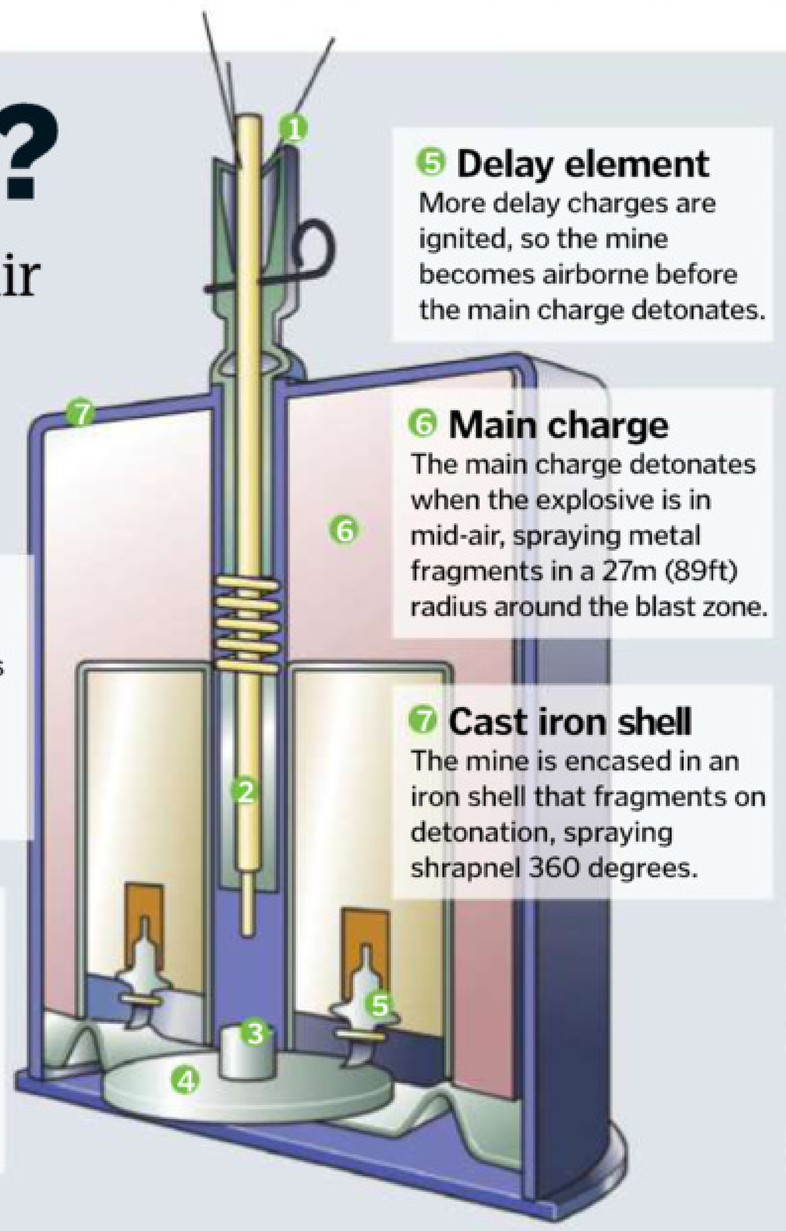
Bounding mines launch into the air before detonating to maximise their damage

1 Prongs
The three prongs of the fuse are pressure sensitive, so when stepped on or pulled by a tripwire, the firing pin is released.

2 Firing pin
The spring-loaded firing pin crushes the explosives in the percussion cap, releasing hot gas and particulates that ignite the delay charge.

3 Percussion cap
A small delay charge activated by the percussion cap acts as a timer, allowing the target to move off before it detonates.

4 Propelling charge
The propelling charge is fired, launching the mine out of its casing into the air, reaching up to 1.7m (6ft) above the ground.



5 Delay element
More delay charges are ignited, so the mine becomes airborne before the main charge detonates.

6 Main charge
The main charge detonates when the explosive is in mid-air, spraying metal fragments in a 27m (89ft) radius around the blast zone.

7 Cast iron shell
The mine is encased in an iron shell that fragments on detonation, spraying shrapnel 360 degrees.

© DK Images; Corbis; Peters & Zabransky

The compound bow

Discover how new-and-improved technology has transformed the traditional bow and arrow into a whole new beast...

The power of the compound bow comes from its construction, comprising three components: a riser and two limbs. The riser is the central part of the bow that is held and is made of aluminium alloy, or carbon fibre, for maximum strength. The limbs are bolted to the riser and are made of a more flexible composite, allowing them to bend to store precious energy as the bow is drawn.

The stiffness of the limbs makes the compound bow much more energy efficient than other designs, with hardly any vibration. The composite construction also provides an advantage over wooden alternatives because it is much less affected by temperature and humidity, enabling the archer to shoot accurately in varying weather conditions.

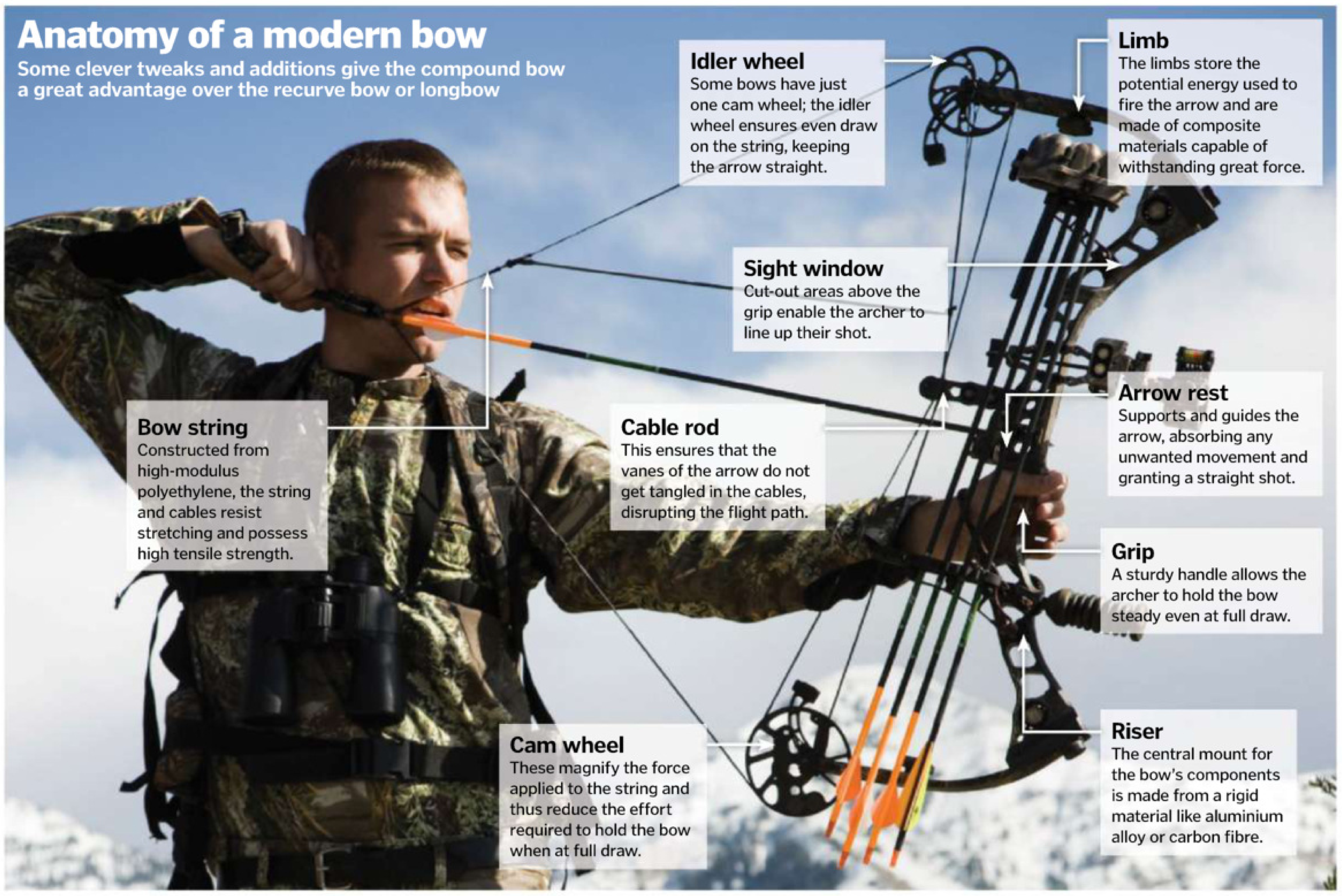
However, the rigidity of the compound bow would make it incredibly hard to draw if the strings were attached directly to the limbs, so a pulley-driven levering system is used. As the string is drawn, the pulleys take in the cables, which draws the limbs of the bow together, storing energy. The system uses asymmetrical cams, so that as the string goes beyond 50-80 per cent of the draw length – towards the point at which the arrow is ready to fire – the amount of force needed to pull the string is reduced. This allows the archer to hold the bow at full draw for longer, granting steadier shooting.

Beyond the bow...

To line up distant shots, archers often use sights with fibre-optic pins – different-coloured pins are set for varying distances, allowing the archer to adjust the shot. Scopes can also be added to magnify the target and increase aiming accuracy. Instead of using their fingers to draw the string, compound bow archers often use a mechanical release. Shaped like a small pincer, the release fits into the hand and pinches the string, enabling the bow to be fired more smoothly; using a release like this makes each shot much more consistent and predictable. Reducing vibration is also important in archery, as any unwanted movement will disturb the path of the arrow. Competitive archers and hunters often attach dampeners to the bow to nullify vibrating.

Anatomy of a modern bow

Some clever tweaks and additions give the compound bow a great advantage over the recurve bow or longbow



Idler wheel
Some bows have just one cam wheel; the idler wheel ensures even draw on the string, keeping the arrow straight.

Limb
The limbs store the potential energy used to fire the arrow and are made of composite materials capable of withstanding great force.

Sight window
Cut-out areas above the grip enable the archer to line up their shot.

Arrow rest
Supports and guides the arrow, absorbing any unwanted movement and granting a straight shot.

Bow string
Constructed from high-modulus polyethylene, the string and cables resist stretching and possess high tensile strength.

Cable rod
This ensures that the vanes of the arrow do not get tangled in the cables, disrupting the flight path.

Grip
A sturdy handle allows the archer to hold the bow steady even at full draw.

Cam wheel
These magnify the force applied to the string and thus reduce the effort required to hold the bow when at full draw.

Riser
The central mount for the bow's components is made from a rigid material like aluminium alloy or carbon fibre.

© Corbis

How bridges are built

The design and technology behind these fundamental structures

All over the globe, bridges come in many shapes and sizes. The humble structure was born by simply balancing a horizontal beam across two pillars. However, as demand grew, wider gaps needed to be crossed and more weight had to be carried. This created the need for arches. Utilised by the Ancient Romans, the arch shape could hold massive amounts of weight and was a revelation in creating larger and stronger bridges. However, arches could only reach a certain length. To cross larger expanses, even longer bridges have to be constructed. These are called suspension bridges. These work using a combination of compression and tension forces that run through a cable system. The road or 'deck' is laid out across these cables, which are strung together with the correct balance of the two forces so it won't buckle or snap under pressure. On most suspension bridges, a tower is placed at either end to take the strain and weight. Iconic examples of these bridges include the Golden Gate Bridge in San Francisco and England's Humber Bridge. Away from the road, bridges are also used for rail and water transport. These bridges are often even longer and stronger as they have to ferry water or huge freight and passenger trains or ferries over vast distances. Seven of the ten longest bridges in the world are located in China, with most of these being rail bridges. As technology and engineering improves, even-more expansive bridges could be in the pipeline. There has been talk of a bridge between England and France and a crossing through the Strait of Gibraltar connecting Europe and Africa. Although it may seem far-fetched, the 16-kilometre (ten-mile) Øresund Bridge that links Denmark and Sweden has demonstrated that cross-country bridges can be constructed successfully.

The Millennium Bridge

Why this famous London structure started swaying

When a new bridge is designed and built, it is essential that all of its construction calculations are absolutely correct. If they are even slightly out, the entire structure could become perilously unstable. Take the Millennium Bridge in London, for instance. Opened in 2000, the bridge experienced sudden and very dangerous sideways movements after the huge crowds who crossed it caused it to sway under the pressure. The eventual solution was to use 91 dampeners underneath the bridge, which absorbed the kinetic energy of the pedestrians' movement and prevented it from wobbling. It reopened fully fixed in 2002 but at a cost of over £5 million ($8 million). An expensive mistake!

Deck
The deck can be made to suit road, rail or even water. It is strengthened by a truss that runs underneath the highway, allowing heavier weights to be transported across.

Compression and tension
The sheer length of suspension bridges means many forces act upon it. The bridge's job is to balance the forces and transfer them to a stronger area that can handle the pressure.

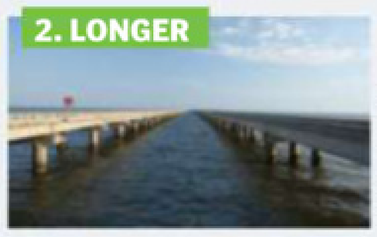
"When a new bridge is made, it is essential that all of its construction calculations are correct. If they are even slightly out, the structure could become unstable"

1. LONG

Rio-Niteroi Bridge

This 13km (8mi) bridge connects Rio de Janeiro and Niterói in Brazil and saves residents a 100km (62mi) commute.

2. LONGER



Lake Pontchartrain Causeway

Many bridges cross the US lake but the most gigantic of them is a huge 39km (24mi) long.

3. LONGEST

Burapha Withi Expressway

This six-lane raised highway in Thailand is the longest road bridge in the world at a sprawling 55km (34mi) long.

DID YOU KNOW? *The world's first-ever iron bridge was officially opened in Shropshire, England in 1781*

The key features of a suspension bridge

How the world's most impressive bridges work

Tower

The strongest areas are the towers at each end. The cables transfer the tension and compression forces to them so the bridge does not buckle or snap under the strain.

Length

The longest suspension bridge in the world is the Akashi Kaikyo Bridge. The 'cable-stayed' technique allows for longer bridge building using more towers to spread out the tension and compression.

Foundations

The cables are anchored into the foundations of the towers. This strong system absorbs the forces acting upon the bridge and diverts the pressure away from the weaker sections.

The statistics...

Akashi Kaikyo Bridge

Year completed: 1998

Years taken to build: 10

Bridge type: three-span suspension bridge

Length: 3,911m

Height: 283m

Deck: Six-lane road

Wind resistance: Up to 290km/h

Earthquake resistance: Magnitude 8.5 Richter

Steel used: 180,000 tons

Concrete used: 1.4 million m^3

Types of bridge

The many ways to bridge and cross a gap

Arch

One of the oldest methods of bridge building, the arch bridge is made by compressing stone, steel and concrete with the finished arch working as a wind bracer. Arch bridges can range from small brick designs to tall and extensive metal constructions.

Suspension

This type of bridge is made of steel plates and cables. Suspension bridges use a combination of tension and compression, which is carried by the cables to towers at either end. The cables transfer the weight to the towers. Their light weight allows them to span long distances.

Beam

Made out of wood or iron, beam bridges are the simplest type of bridge construction. The weight is put on two support girders on either side of the crossing. The earliest examples of beam bridges came in the form of humble logs or tree trunks across streams and rivers.

Cable-stayed

The cable-stayed bridge is one of the most common in contemporary bridge building. They have one or more towers, each of which uses vertical compression to move the forces from the cables through to the foundations, reducing the strain and stress on each part of the bridge.

Bascule

Also known as a drawbridge, it ranges in size from a medieval feature to larger structures like Tower Bridge. Usually powered by a counterweight and winch, similar designs include a vertical-lift bridge that rises straight up and a swing bridge that can pivot horizontally to open up.

© Rich Niewiroski Jr; Thinkstock; Corbis

Underwater buildings

With land in short supply, it's little wonder more and more architects are looking beneath the waves for inspiration...

Submarines have been around since at least the 18th century and modern nuclear subs can reach depths of over 400 metres (1,300 feet). By comparison, building a house just ten or so metres (33 feet) below the surface might seem easy by comparison, but permanent dwellings have their own set of unique challenges. Let's start at the front door. A submarine rises to the surface to let people on and off. This means the air inside the sub can be kept at normal atmospheric pressure. But a completely submerged building anchored to the seabed either needs an airlock, so the pressure can be adjusted as divers enter and exit, or it needs to keep its internal air pressure the same as the water pressure outside.

When you spend more than an hour or so breathing high-pressure air, the nitrogen in the air dissolves into the water stored in your body tissue. Without an extensive period of gradual decompression at the end of your stay, the nitrogen will come out of solution all at once and form bubbles that can cramp muscles and block blood vessels. This is a potentially lethal condition known as 'the bends'.

To avoid this risk, most undersea buildings currently being planned have a permanent access link to the surface. This allows the air pressure throughout the building to be kept at normal atmospheric levels, but it means that there is nothing balancing the huge weight of the water outside. At a depth of 20 metres (66 feet), each square metre of wall or window has more than 20 tons of weight pressing against it. This requires much thicker and stronger materials than a normal house, plus walls and roofs have to be curved to distribute the load evenly. A permanent connection to the surface also exposes the building to tidal forces.

The Underwater Room at Tanzania's Manta Resort is a single-bedroom hotel in the Zanzibar archipelago. To avoid the constant scouring of the twice-daily four-metre (13-foot) tides in the island chain, this room isn't firmly anchored to the seabed. Instead it hangs below an upper deck that floats on the surface. The effect is rather like an extreme version of a glass-bottomed boat.

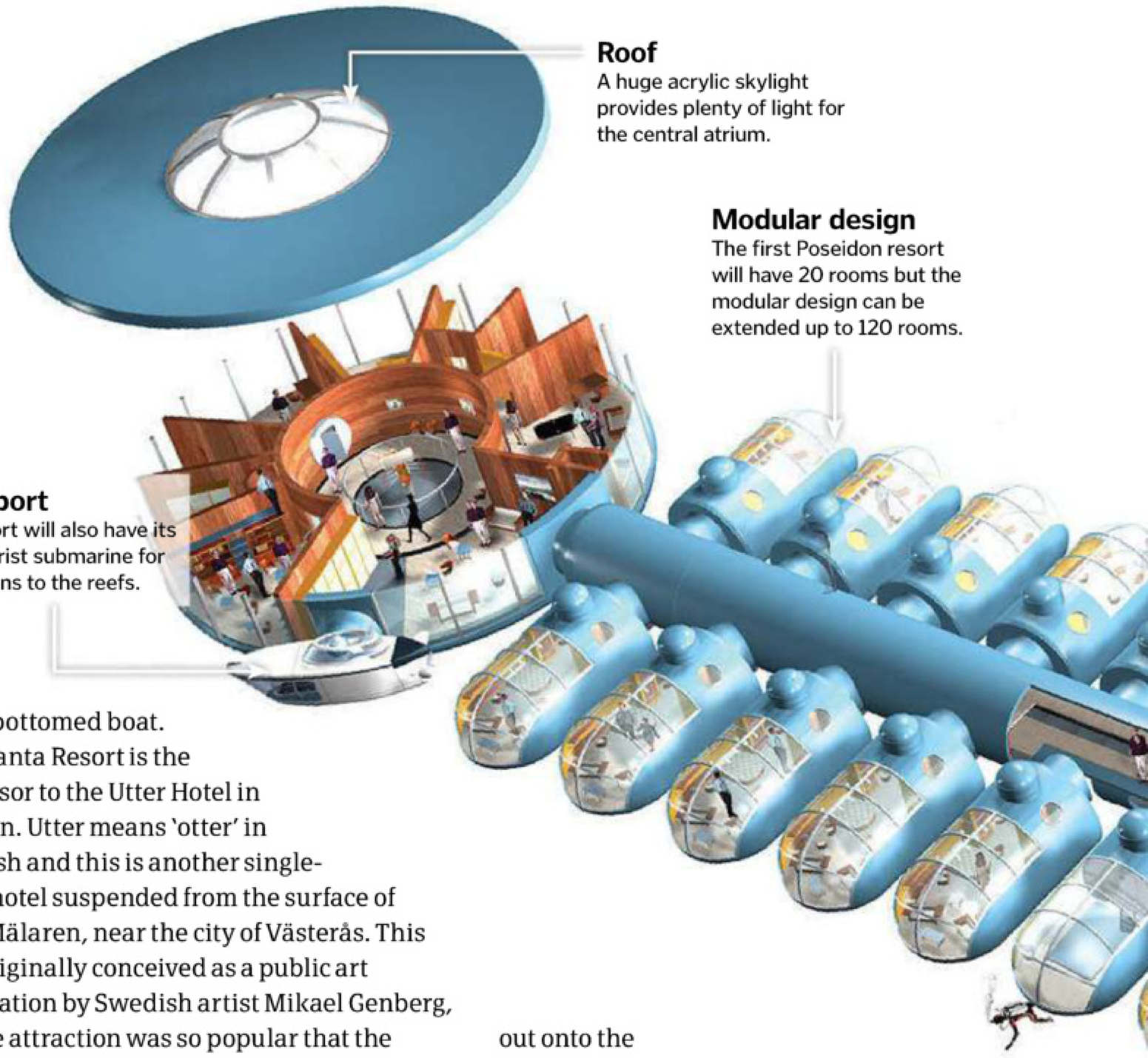
The Manta Resort is the successor to the Utter Hotel in Sweden. Utter means 'otter' in Swedish and this is another single-room hotel suspended from the surface of Lake Mälaren, near the city of Västerås. This was originally conceived as a public art installation by Swedish artist Mikael Genberg, but the attraction was so popular that the Genberg Underwater Hotels Company was formed in 2006 to bring the concept to warmer waters around the world.

More ambitious designs have floors raised entirely above the sea surface, as well as anchored below it, with the two levels connected by narrow support piles. The Water Discus Hotel is an ambitious project proposed for the Maldives that looks like a landed spaceship. The upper levels are supported high enough above the water to survive a medium-sized tsunami, while the undersea level sits ten metres (33 feet) deep with 21 bedrooms that look out onto the specially lit coral reef.

Dr Lech Rowinski chairs the Department of Theory and Ship Design at Gdansk University in Poland. He is a cofounder of Deep Ocean Technology, the company behind the Water Discus Hotel. In an exclusive interview with **How It Works**, he told us about the challenges of the project: "For us, wave action is the biggest problem, because we are necessarily limited to areas with low tidal ranges. We have the opposite design to an oil rig, where you build high above the water just to avoid the waves. In our case we have a

A new Poseidon adventure

One of the marine habitats currently under construction, take a tour around the Poseidon Undersea Resort now



5 TOP FACTS
AQUATIC ABODES

Aquatica
1 An old submarine refuelling base is turned into a medical research base in *Deep Blue Sea* (1999). Surprisingly, breeding super-intelligent mutant sharks turns out to be a bad idea.

Broken Ridge
2 In the Nineties TV series *seaQuest DSV*, land resources are exhausted and underwater mining towns line the ocean floor. Broken Ridge is off the coast of Australia.

Tri-Oceanic Corp
3 In *Leviathan* (1989), undersea miners plan to spend 90 days at the bottom of the Atlantic Ocean. But then they find a contaminated shipwreck and start sprouting tentacles.

Deep Core
4 The deep-sea platform in *The Abyss* (1989) sits an alarming 2km (1.2mi) under the sea. That's peanuts compared to the aliens living in the 8km (5mi) ocean trench though.

Atlantis
5 Not just the lost city of Greek legend, but also the secret undersea lair of supervillain Karl Stromberg from the 1977 Bond movie *The Spy Who Loved Me*.

DID YOU KNOW? *To hire the entire Poseidon Undersea Resort exclusively for a week will cost $2.75mn (£1.67mn)*

The Poseidon underwater resort is located in Fiji

Arrival pontoon
Guests arrive by boat to the floating entrance platform.

Elevator
Two lifts carry guests down to the sea floor up to 20m (66ft) below.

Service schedule
Each pod can be floated individually to the surface for servicing. Normally this should only be necessary every ten years or so.

Total displacement
The whole resort will weigh around 6,480 tons and measure 128 x 24m (420 x 80ft).

On-site education
Resident naturalists provide talks for guests on the local marine habitat.

Acrylic windows
Each curved pane in a Poseidon resort is 3 x 2m (10 x 6ft) and 10cm (4in) thick to withstand the external pressure.

Artificial coral reefs have improved massively over the years and today are much more eco-friendly

Keeping green

Coral reefs are fragile structures and living polyps are very sensitive to pollution levels. In the Seventies, attempts to construct an artificial coral reef out of millions of old car tyres off the Florida coast turned into an environmental catastrophe as the tyres not only failed to attract new corals but broke loose and caused extensive damage to existing reefs. Modern undersea construction uses buildings anchored on piles so they have minimal contact with the seabed, using materials that encourage coral growth on their surface. All waste and effluent is recycled or removed in order to not contaminate the water.

substantial volume under the water so there are huge forces acting on it." Surprisingly, the solution is not to sink deep foundation piles into the bedrock. Instead the Water Discus Hotel will be anchored to the seabed using suction. It works a bit like a Wellington boot that gets stuck in deep mud, except that the mud in this particular case is a steel-walled cavity that the hotel base sits in. "It's a question of not allowing water *under* the structure," explains Dr Rowinski: "You have a cavity – it doesn't need to be water-tight, but with very limited flow. Pumping the water out isn't required because it is a dynamic system. One moment you have lower pressure at the bottom of the wave and another moment you have higher pressure, so you only need a small overall force keeping the base of the hotel in the cavity."

The walls of underwater buildings are made from steel, using shipbuilding techniques, but the large windows are made from acrylic plastic. It flexes slightly to avoid stress fractures, but more importantly it has a refractive index very similar to water, so it doesn't interfere with the view. It is also the reason underwater hotels are sited no deeper than 30 metres (98 feet) below the surface. "It's a question of visibility," says Dr Rowinski: "We need to provide some colour for objects in the water and if you want colour you need shallow water."

But even ten metres (33 feet) of water presents a significant problem in the event of an emergency evacuation. Ironically, fire safety is actually a major consideration in an aquatic building because even a small fire can quickly consume the available breathable air. The Water Discus Hotel is designed so that the entire underwater section can rise to the surface. Dr Rowinski explains: "We designed the ballast tanks above the water level so you can raise the structure easily, without the aid of any mechanical equipment. It rises under its own buoyancy. It would take at least 15 minutes to rise, but we think this is actually too fast, so we aim for half an hour. This is for organisation of the evacuation – to allow people to move without panicking."

And if you happen to be concerned about the risk of hurricanes or tropical storms, an underwater holiday might actually be the safest destination for you. "I think the hotel will be more resistant to weather than buildings on land," concludes Dr Rowinski: "In the Maldives, very high waves during tsunamis are very likely so it's safer to be in the underwater compartment than on the shore."

This underwater suite is part of a luxury hotel in the Maldives

Ocean homes

While a week-long luxury holiday or research trip might be enough for most of us, if you want something more permanent, there are now a few companies that will build you a permanent undersea residence. US Submarine Structures LLC is currently constructing two-bedroom circular houses that can be anchored to the seabed of your choice. The 'H_2OME' project can cope with depths between ten and 20 metres (33-66 feet) and is connected to the surface via a lift in the central pillar. This means the air inside the house is the same pressure as the surface, so there is no need for airlocks or lengthy decompression procedures when you leave. The panoramic acrylic windows extend around the house, offering views from every room. Each habitat features over 460 square metres (5,000 square feet) of living space, complete with luxury furnishings and décor inspired by five-star hotels and superyachts.

Evolution of undersea habitats

1962

Conshelf I

Designed by Jacques Cousteau, the Continental Shelf Station is the first inhabited underwater building. Two 'oceanauts' spend a week in this 5 x 2.5m (16.4 x 8.2ft) cylinder.

1964

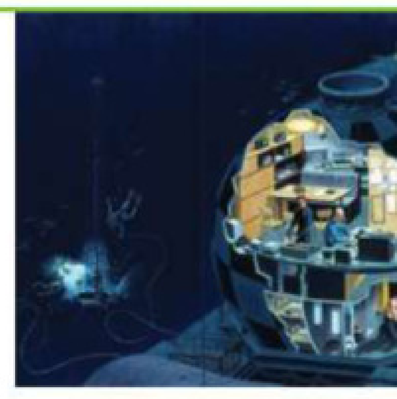
SEALAB I

Built by the US Navy to study techniques to reduce decompression sickness after diving for extended periods. It spends 11 days at 58m (190ft) depth.

1965

Conshelf III

The last of Cousteau's underwater habitats (right). At 100m (328ft) below the surface – ten times deeper than Conshelf I – it is self-sufficient for three weeks.



THE STATS
WATER DISCUS HOTEL SPECS

ROOMS 21

1,000m² FLOOR AREA

DEPTH 10m

DIAMETER 49m

2017 COMPLETION DATE

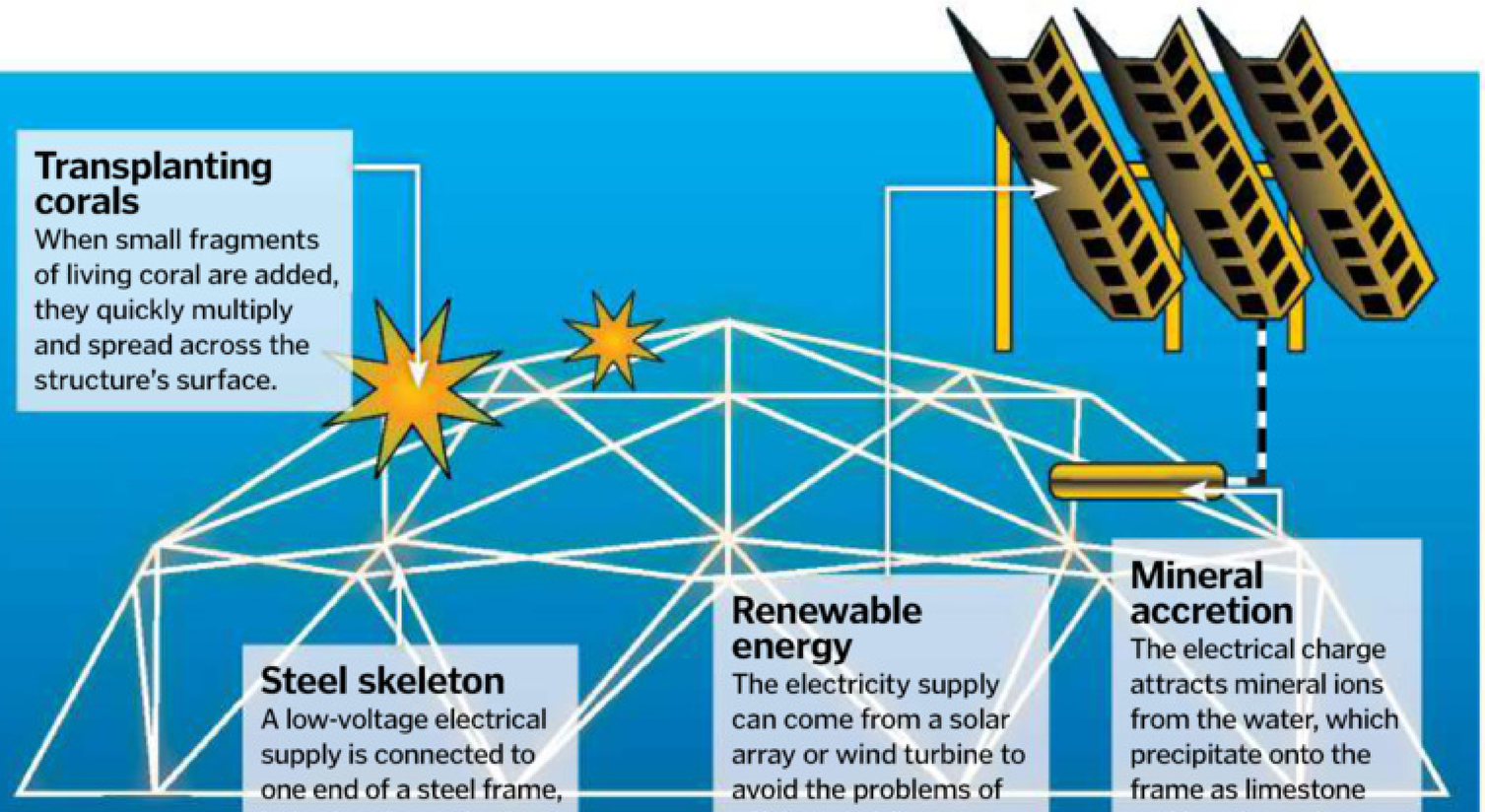
$50-120mn ESTIMATED COST

DID YOU KNOW? *In 1966, a Soviet amateur diving club built a series of underwater habitats (The Ichthyander Project) in the Black Sea*

Make a living building

A coral reef is made mostly from calcium carbonate (limestone). The coral polyps living there absorb mineral ions from the seawater and deposit it as solid rock around their bodies to form an exoskeleton. Biorock harnesses these same mineral ions but uses electricity instead of living corals to precipitate them as solid rock. The electrically charged ions can be attracted onto a metal surface by running an opposite charge through the metal. This only needs a low voltage, harmless to marine life and by varying the current you can adjust the mineral formation.

In theory, Biorock could let us 'grow' a building (see diagram). Although it uses more energy to produce than ordinary concrete, it is three times stronger and can take any shape. The layer grows at up to five centimetres (two inches) a year and damage from storms or collisions can heal itself, provided the power stays on. And far from harming marine life, corals attached to Biorock actually grow faster and tolerate worse sea conditions than corals on natural reefs.



We may soon literally sleep with the fishes in marine H_2OMEs currently under development

The 21 suites of the Water Discus Hotel will be located 10m (33ft) below the surface, surrounded by coral reefs

1968

Helgoland
The first underwater habitat built for cold waters, Helgoland is a 14 x 7m (46 x 23ft) cylinder that operates in the North and Baltic seas.

1969

Tektite
This 15m (49ft)-deep research habitat comprises two metal cylinders on a rectangular platform with a flexible tunnel connecting them.

1970

Hydrolab
Over 15 years, Hydrolab hosts 180 separate missions. Four scientists can live for weeks at a time in the 6m (20ft) cylinder (right).

1986

Aquarius
Still in use today, it weighs 73 tons and can be deployed in water up to 37m (120ft) deep. It has six bunks, a shower and a Wi-Fi connection.

2005

Ithaa
This restaurant in the Maldives (right) sits 5m (16.4ft) below the surface. Diners enjoy 180-degree panoramic views while they eat.

© Poseidon Undersea Resorts; Karline Rousseau Design Studio; Deep Ocean Technology; Conrad Hotels & Resorts; NASA; NOAA; Getty

Construction of tunnels

Discover the technology that blazes trails through solid rock

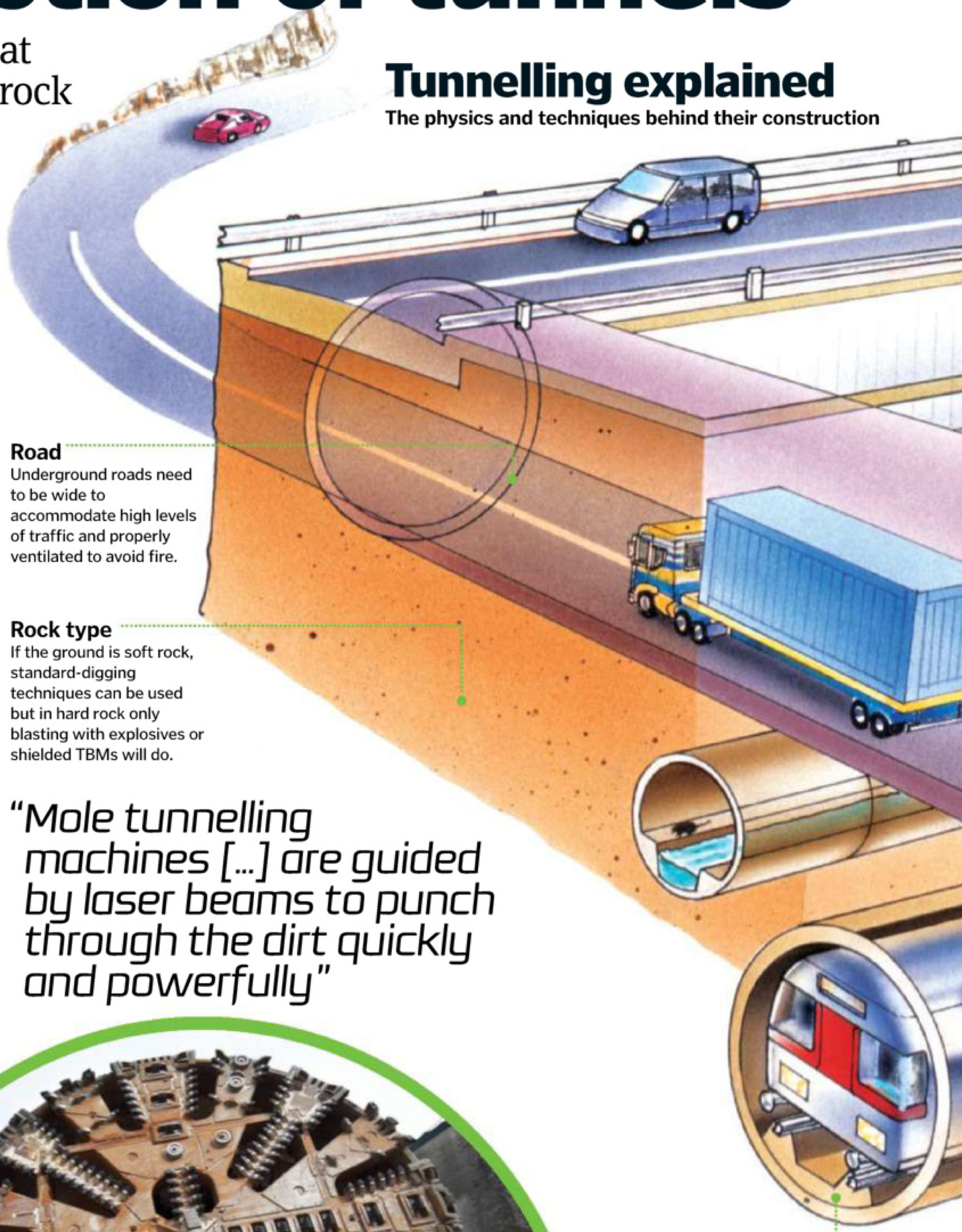
From mining to transport infrastructure and sewage control, tunnels are essential for an array of purposes. The longest in the world is the Delaware Aqueduct in the United States at an astonishing 137 kilometres (85.1 miles) long. The Seikan Tunnel, linking the Japanese islands of Honshu and Hokkaido, is the longest rail tunnel and spans a mighty 54 kilometres (33.4 miles). However, by 2016 it will be trumped by the Gotthard Base Tunnel (GBT) in Switzerland, which will be three kilometres (1.9 miles) longer.

To start a tunnelling project, you must first plan a geologic analysis of the area. By making a judgement on the rock and soil type, a construction's properties and dimensions can be adjusted accordingly. For example, you would use lighter materials and equipment on softer rock. An initial opening is made first, which is held up by rock bolts and a shotcrete lining to stop the structure from collapsing during construction. There must also be plenty of ventilation shafts to avoid any chance of suffocation, poisoning or heat exhaustion. Only then can the construction of a tunnel get under way in earnest.

Since 1954, large projects have used 'mole' tunnel boring machines that are guided by laser beams to punch through the dirt quickly and powerfully. A technique known as the immersed-tube method works by inserting prefabricated tunnels into a previously dug trench. This procedure has been found to be extremely effective, especially in underwater developments. In smaller constructions, hand tunnelling is still frequently used as it is much more cost effective than using a giant machine to carve pathways through rock.

Tunnelling explained

The physics and techniques behind their construction

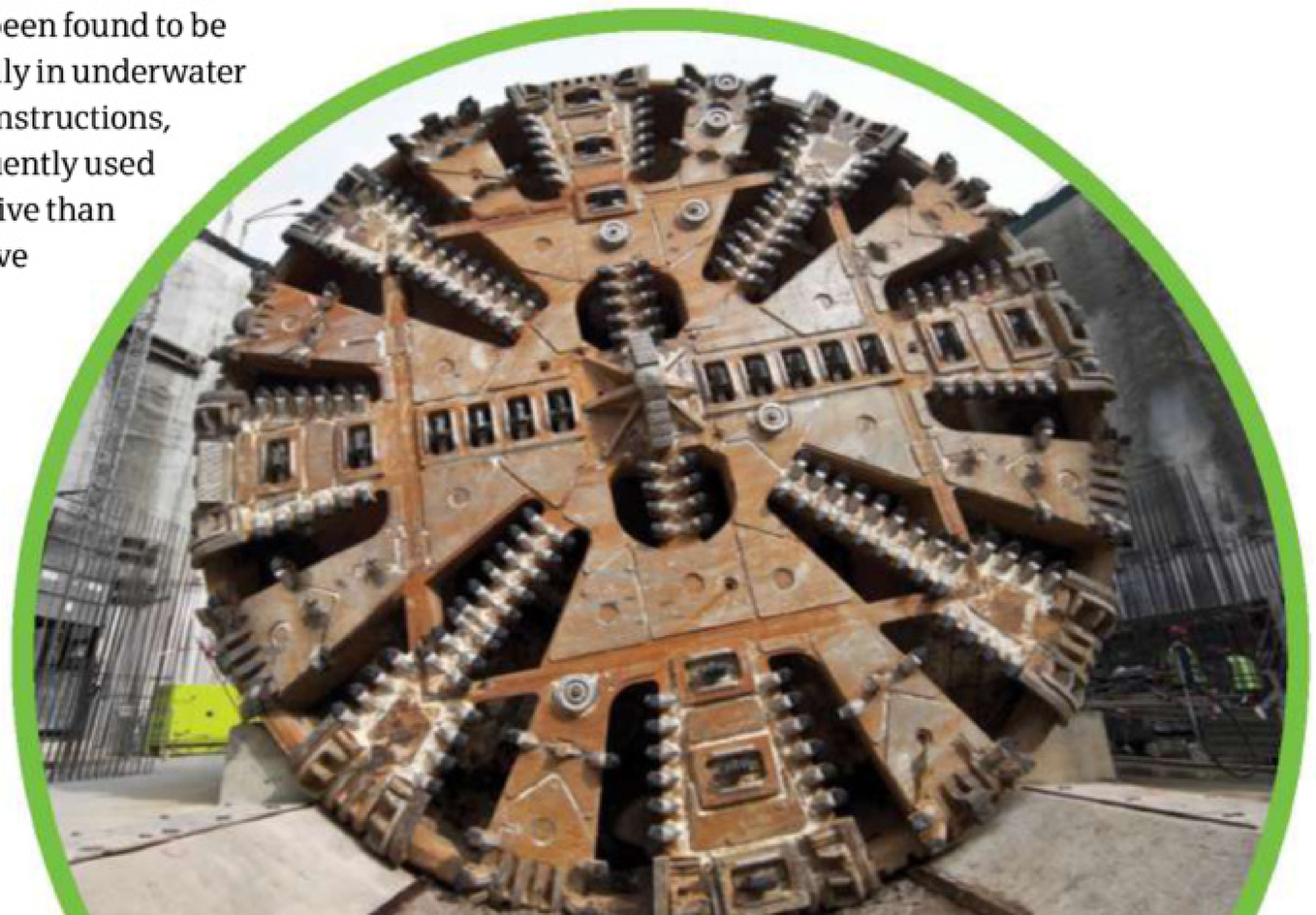


Road
Underground roads need to be wide to accommodate high levels of traffic and properly ventilated to avoid fire.

Rock type
If the ground is soft rock, standard-digging techniques can be used but in hard rock only blasting with explosives or shielded TBMs will do.

"Mole tunnelling machines [...] are guided by laser beams to punch through the dirt quickly and powerfully"

Railway
Tunnel boring machines (TBMs) construct underground railway tunnels by using a rotating cutter with a force equivalent to lifting over 2,900 London taxis.



RIGHT A tunnel-boring machine head like the one used on mole tunnelling machines

154km

THE REAL LONGEST TUNNEL?

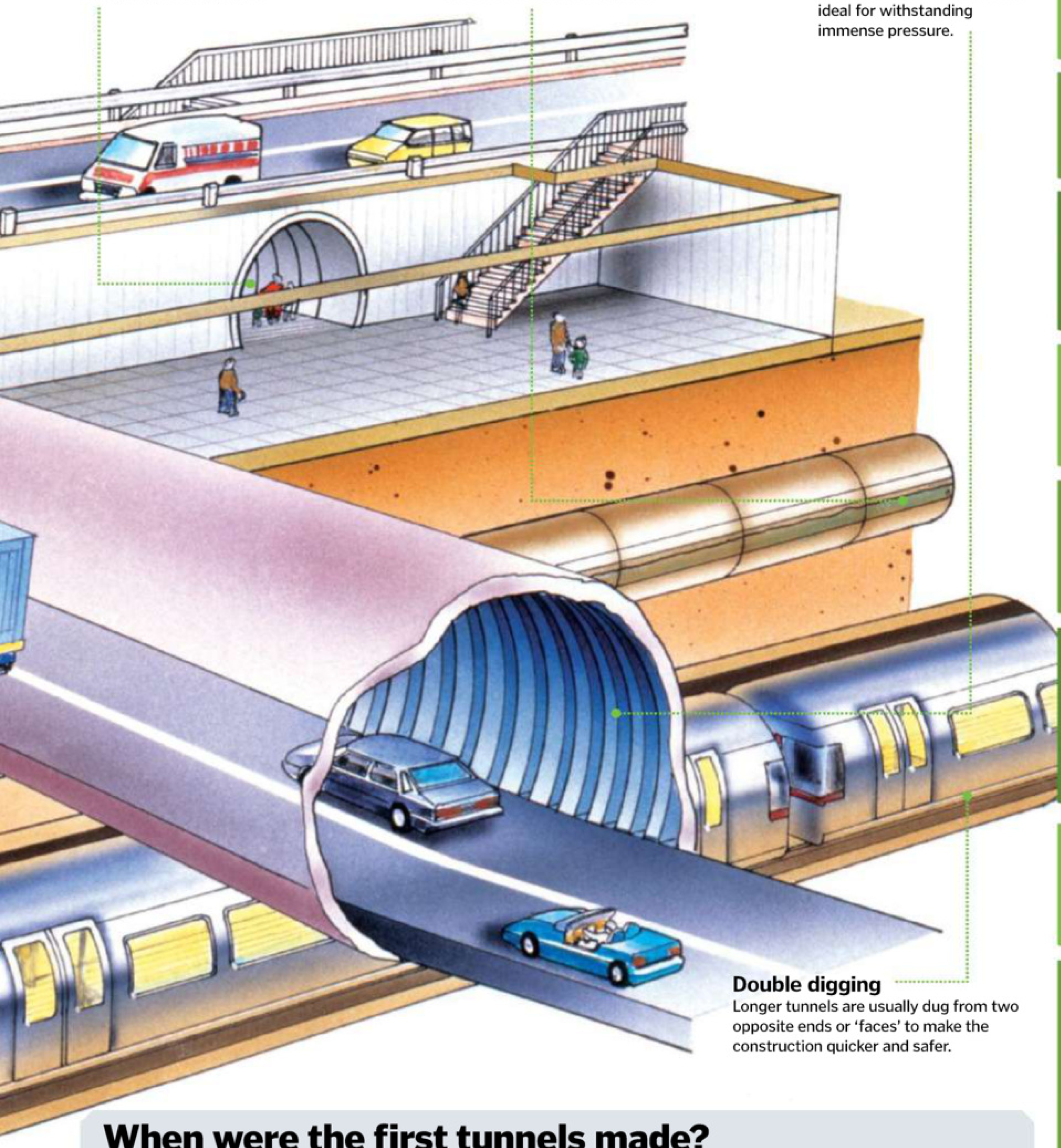
The Thirlmere Aqueduct was constructed in Northwest England in 1925 and would be the longest tunnel in the world if its length was continuous and didn't have gaps in it.

DID YOU KNOW? *The TBM 'Bertha' is named after Bertha Knight Landes, the first female mayor of a major US city*

Pedestrian
Underpasses are designed to relieve congestion on the streets and can be made quickly as they are only constructed marginally below ground.

Wastewater
Cities use huge sewage systems made of tough interlocking concrete segments to ferry waste to out-of-town treatment farms.

Inverts and crowns
The bottom half of a tunnel is called the invert while the topside is a crown. An arch is an incredibly strong structure ideal for withstanding immense pressure.



Double digging
Longer tunnels are usually dug from two opposite ends or 'faces' to make the construction quicker and safer.

23 METRES WIDE
The Yerba Buena Island tunnel is the largest single-bore tunnel

15 MILES
Longest road tunnel in the world is the Lærdal Tunnel

38 KILOMETRES UNDERWATER
The Channel Tunnel has the longest undersea portion of any tunnel

54 KILOMETRES
The longest rail tunnel is the Seikan Tunnel

4.9km
The Fenghuo Mount Tunnel is the highest tunnel on Earth

600
tunnels in the Netherlands have been built to help the local endangered animals

240 METRES BELOW SEA LEVEL
The Seikan Tunnel is also the deepest rail tunnel

175 METRES UNDERGROUND
The Large Hadron Collider in Switzerland

30 MILLION TONS
Rock that has been blasted out of the Alps to make the St Gotthard Base Tunnel.

When were the first tunnels made?

As civilizations prospered and grew, natural obstacles like mountain ranges had to be mined through to gain access to other valleys as well as locating natural resources and precious gems. The first tunnels were built in Ancient Egypt and Babylon and were used primarily for irrigation. Constructions became more ambitious in the Roman era with the Cloaca Maxima in Rome an example of improved engineering. The first railroad tunnel built for US railroads was the Staple Bend Tunnel on the Allegheny Portage Railroad in 1833. Nearly 11,400 cubic metres (402,300 cubic feet) of rock were blasted out to construct it. In the 19th century, tunnels were built using a tunnelling shield first created by Marc Brunel (father of the famous Isambard) in 1825 and improved upon by Peter Barlow and James Greathead in the 1880s. This system would protect miners under a reinforced hood that shielded them from water and rubble. Since the start of the 20th century, huge projects, including many in the Alps such as the Mont Blanc and Arlberg Tunnels, have helped to develop new ventilation and water management techniques.

© Thinkstock

Under the Wimbledon roof

The technology that means rain no longer stops play

Tennis is a sport that requires good weather, so it's surprising that one of its premier competitions has been held in rainy England since 1877. So after 132 years and countless rain delays, a roof was built on Wimbledon's Centre Court for the 2009 Championships. The primary function is to keep water off of Centre Court so games can continue when a downpour begins, but it also means games can continue after dark.

The roof spans 5,200 square metres (56,000 square feet) and is made up of a translucent membrane held up by ten steel trusses, each weighing around 70 tons.

John Biggin was project manager of the build and explains how the roof closes: "The whole system is electrically powered. Actuators push on V-shaped arms, which flatten out, pushing each truss apart. These run on bogies, spreading along rails until the roof is covered."

It only takes around eight minutes to close but the lights and air management system take up to half an hour to get working. The roof cuts out 60 per cent of the natural light so 120 specialist sports lights are used to provide the correct lighting levels required for both the match and the television broadcasts. The air-conditioning system regulates the temperature and removes moisture from inside the stadium so conditions are as similar to a roofless atmosphere as possible.

"The main challenge was the design," says Biggin. "We used the concertina because of space restrictions but we built a model at Sheffield so we knew it worked. It's the only one in the world." The Wimbledon roof has revolutionised one of the world's most famous sporting events by allowing matches to go on long after dark or while the traditional rain is lashing down all around.

Up on the roof

How this ace roof is set to serve Centre Court for years to come

1 Control gear boxes
These gear boxes operate the actuators.

2 Trusses
Each of the ten steel trusses that span the court weighs 70 tons.

3 Actuators
Electronic actuators push down on the arms between the trusses.

4 Arms
As the arms are pushed, they spread the trusses apart, closing the roof.

5 Lights
120 sports lights are carefully arranged so the court is evenly lit.

6 Bogies
The trusses run on these wheeled trolleys that run along a rail.

7 Locking arms
Arms across the top of the roof lock in place to withstand wind and rain.

8 Time
It takes between eight and ten minutes for the roof to close.

THE STATS

GAME, SET, STATS

TOTAL WEIGHT 3,000 tons

WIDTH 77m

LENGTH 65m

BUILT 2009

CLOSING TIME 8-10 mins

LIGHTS 120

DID YOU KNOW? *Amelie Mauresmo and Dinara Safina were the first players to play under the new Centre Court roof*

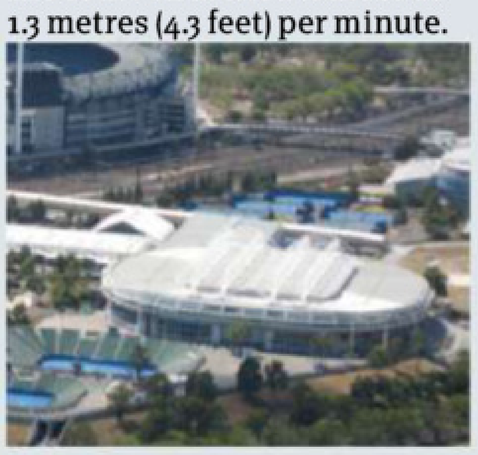
Incredible retractable roofs

Rogers Centre, Toronto

When it was finished in 1989, the Rogers Centre became the first sports stadium in the world to have a retractable roof. Constructed from four huge steel panels, the 11,000-ton roof slides away in just 20 minutes.

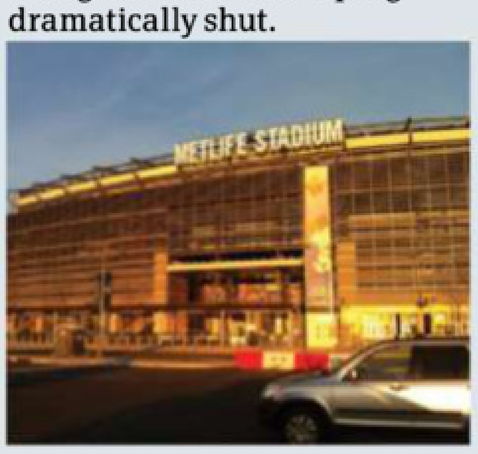
Rod Laver Arena, Melbourne

The venue for the Australian Open final has a retractable roof, vital for a venue that experiences scorching temperatures and lashing rain. The rust-proof roof takes 20 minutes to shut, rolling over the court on arched trusses at 1.3 metres (4.3 feet) per minute.



New Atlanta Stadium, Atlanta

The proposed new home of NFL team Atlanta Falcons will sit beneath a mind-boggling roof. It will close like a camera lens, its eight sections swooping dramatically shut.



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Inflatable concert halls

Listen out for the world's first pop-up concert hall

Tuba players around the world had better take a deep breath because they might soon have to blow up their own concert halls if this incredible project is anything to go by.

Artist and sculptor Anish Kapoor and architect Arata Isozaki teamed up to create this amazing 18-metre (59-foot) high and 36-metre (118-foot) long by 29 metre (95 feet) wide structure, which held a series of concerts at Matsushima, Japan. The project came about in order to bring a bit of joy back to the group of islands on Japan's northeastern coastline, which was decimated by a tsunami after the catastrophic earthquake in 2011.

It's made of a stretchy plastic membrane that can be inflated by pumping gallons of air into it and deflated quickly. It can fit 500 audience members inside its stylish walls, as well as the orchestra. It took two years of planning and uses key parts of the local landscape in its design, such as cedar trees that were destroyed in the disaster being used for seating.

The air-conditioning system is cooled by giant blocks of ice and the revolving doors have been specially created in Germany with completely airtight seals, so no air is able to escape from inside the dome. Huge fans keep the air pushing against the PVC-coated membrane, so the entire structure doesn't collapse around the spectators.

This amazing design can fully inflate in just two hours despite its huge size. Although unlikely to replace Sydney or Moscow as the world's most iconic opera houses, it could make a massive impact with pop-up buildings in disaster areas based on the same principles.

An inflatable hall in standby mode

How to inflate a concert hall

How do you make a 500-seat hall stay up?

Keeping grounded
The structure is connected to the ground by being secured on a heavy metal frame.

Air conditioning
Fans circulate the air around the structure from behind blocks of ice that help keep the audience and performers cool.

DID YOU KNOW? *The Ark Nova was called that because the architects saw it as 'The New Ark', bringing hope after the floods*

Concert hall concepts

The Sydney Opera House is one of the most instantly recognisable buildings in the world. It took 16 years to build and beat competition from 232 other entries. It cost over AU$100m to build and its roof sections weigh 15 tons.

No less striking, the Bolshoi Theatre in Moscow is a symbol of Russian architecture and resilience. Burned down twice before being rebuilt into the huge structure seen today in only three years, it can seat 1,740 people.

Opened in 1778, Milan's La Scala is believed to be the finest opera house in Europe. The very first opera put on was *Europa Riconosciuta*. It has 2,800 seats, with the very top rows called the loggione – where all the fiercest critics choose to stand.

Possibly the most iconic music hall in the world is in Sydney

Acoustic cloud
This helium-filled balloon not only helps the dome stay up but also bounces sound back for acoustic assistance.

Material
A PVC-coated polyester fabric is used, as it has high tensile strength but can also be deflated easily then packed away tightly.

Seating
Seats are created from cedar trees that got knocked down during the 2011 tsunami.

Entrance
At the entrance is a tightly sealed revolving door that doesn't let air out.

© Lucerne Festival/ARK NOVA

CONTROLLING THE WEATHER

DISCOVER HOW WE MAKE RAIN AND THE AMBITIOUS PLANS BEING HATCHED TO TACKLE CLIMATE CHANGE

Superhero Storm in the *X-Men* comics can conjure rain, end droughts and create hurricanes with the power of her mind. Now, scientists and meteorological technology are opening more and more opportunities for us mere mortals to manipulate weather and Earth's climate.

In 2009, Chinese meteorologists from the Beijing Weather Modification Office claimed to be responsible for the city's earliest snowfall since 1987. Around 16 million tons of snow reportedly fell over drought-afflicted northern China after workers fired rockets carrying pellets of silver iodide into heavy clouds.

The rockets were cloud seeding, a process invented in the late-Forties. Supporters claim it can reduce hail damage, increase rainfall and disperse fog among other things. There are cloud-seeding projects in at least 20 countries worldwide, from Israel to Australia; in 2003, in the US alone, ten states were conducting at least 66 cloud-seeding programmes. In China, around 32,000-35,000 people are employed in the weather modification industry.

The big question in cloud seeding is: how effective is it? A 2003 US National Academies report concluded there was no concrete scientific proof it worked. According to Professor Michael Garstang from the University of Virginia, who chaired the report, the situation hasn't changed much since; there remains "a lack of definitive evidence," he says.

Even cloud-seeding supporters admit it doesn't currently lead to a huge rise in rain and snowfall. "It doesn't increase precipitation by 50 per cent in most cases," says Bruce Boe from Weather Modification Inc, a private weather control company based in North Dakota, USA.

US enthusiasm for weather modification research waned in the late-20th century, with funding falling to less than five per cent of its Seventies peak. But there are signs of fresh interest in the field. The US National Science Foundation (NSF) is funding a cloud-seeding project in the Wyoming mountains, operated by Weather Modification Inc. New technology, such as advanced computer models and radar instruments that can see inside clouds is driving the resurgence of interest, says Boe: "We're bringing a lot of new tools to bear on the question. These tools weren't available before and they're starting to bear fruit."

The Wyoming project, launched in 2005, uses aircraft-mounted radar and ground-based

5 TOP FACTS
MYTHS BUSTED

Geoengineering is ready
1 Today's geoengineering ideas are untested or small-scale experiments. Cooling Earth by one degree Celsius would require a minimum five years of military-scale effort.

One tech is enough
2 No single 'magic technology' can cool the Earth. Future geoengineers might use many fixes, like reflective buildings, a space-based deflector and encouraging reforestation.

It solves climate change
3 Geoengineering doesn't stop greenhouse gas emissions – the root cause of man-made climate change. It's a 'plaster', pausing harmful warming to give us time to cut emissions.

We can't create rain
4 There's emerging evidence that cloud seeding *can* make rain. An Australian project in 2005-2009 found that rainfall increased in suitable clouds by an average 14 per cent.

It's all a conspiracy
5 There's no scientific evidence behind claims that HAARP, a US facility studying Earth's ionosphere, is a secret conspiracy for creating hurricanes as weapons.

DID YOU KNOW? *A global survey in 2010 found 72 per cent of us supported research into reflecting sunlight to cool the planet*

instruments. It tests the effectiveness of seeding winter orographic clouds – which are cold clouds formed when air rises over mountains – with silver iodide.

"In the mountains of the American West, these types of storms are the main target for cloud seeding. Often the clouds are not efficient at generating snow, so cloud seeding is used to enhance snow production," says Dan Breed from the US National Center for Atmospheric Research (NCAR), who is evaluating the project.

Another aim of the experiment is to increase snowfall by perhaps ten per cent a year, building up the winter snowpack so it's available for use. The extra water running off the mountains each spring would be worth an estimated £1.5-3 million ($2.4-$4.9 million).

Cloud seeding affects the weather in a local region, but there are other technologies being devised to alter climate on a much bigger scale. Space mirrors and giant floating hosepipes might sound far-fetched, but they're two proposals for geoengineering. Geoengineering is deliberate global modification of Earth's climate to counter man-made climate change.

Geoengineering may sound impossible, but serious scientists are investigating how it might cool down the planet. In the last few years, billionaire Bill Gates reportedly donated £2.8 million ($4.5 million) to geoengineering research, and the UN IPCC report, a summary of what most scientists agree we know about climate change, mentioned geoengineering for the first time this year.

Geoengineering is essentially 'Plan B' in case we reduce greenhouse gas emissions 'too little, too late' to avoid dangerous climate change, argues a 2009 report by the UK's Royal Society. A temperature rise of just two degrees Celsius (3.6 degrees Fahrenheit) could melt the Greenland ice sheet and cause a long-term sea level rise of seven metres (23 feet). That's enough water to submerge both London and Los Angeles.

To avoid this wide-scale warming, we'd need to cut global carbon dioxide emissions by 50 per cent of 1990 levels by 2050, according to the Royal Society. Yet emissions are still rising – by 1.4 per cent during 2012. Even if we cut carbon emissions today, temperatures will continue rising for decades. The climate system is like an oil tanker – ie slow to turn around.

Dr Hugh Hunt is an engineer from Cambridge University working on SPICE (Stratospheric Particle Injection for Climate Engineering) – a UK government-funded geoengineering research project: "We don't know what the scale of unabated climate change will be," he says. "You've got to think in advance what emergency measures you might need, and then hope you won't need them."

There are two types of geoengineering. Solar radiation management (SRM) cools the Earth by reflecting the Sun's heat back into space, while carbon dioxide removal (CDR) scrubs CO_2 – the primary greenhouse gas causing man-made climate change – from the atmosphere.

Examples of SRM include space mirrors, injecting sulphate aerosols into the atmosphere through giant hosepipes and painting urban roofs white. One idea uses cloud seeding to make clouds more reflective. Fleets of unmanned 3,000-ton barges could sail the oceans, spraying clouds with saltwater. Salt particles should create more water droplets in the clouds, whitening them. Proposals for CDR include fertilising tiny marine plants with iron, growing new forests or fast-growing crops and burying charcoal, all of which lock up CO_2 and remove it from the air. Most geoengineering proposals remain in the lab at this stage.

"We can do very little right now because the

Geoengineering plans include ideas for orbiting sunlight reflectors in space

Special barges could send up sea salt to whiten clouds and help reflect sunlight

New technology has led to a resurgence in cloud-seeding projects

© John MacNeill Illustration; SPL; Weather Modification Inc./Bruce Boe, Christopher Grilliot; Peters & Zabransky

Weather-changing tech in action

Discover the machines and techniques capable of adapting Earth's climate

Space mirrors
A giant sunshade made of tiny mirrors could be put into orbit to cool the Earth. Taking decades and trillions of dollars to deploy, its effect on our weather is unknown and it would not stop the oceans acidifying.

Reflective buildings
Painting roofs white and brightening roads/pavements should help bounce the Sun's heat back into space and cool the Earth, but some scientists believe white roofs could reduce cloud formation and increase warming.

Enhanced weathering
This would involve spreading crushed olivine – a silicate mineral – over agricultural land, which chemically reacts with CO_2 to produce alkaline limestone; this could then be used in the ocean to reduce acidity. A simple idea, but would require huge mining and chemical plants.

Artificial trees
These towering machines would scrub carbon dioxide from the air, turning it into liquid that can be stored in porous rocks beneath the oceans. Millions of artificial trees would be needed and the CO_2 needs storing for millions of years.

Reflective crops
Certain crops, shrubs and grass reflect more sunlight back into space than others. This would be cheap to implement, but needs a huge land area and has unknown effects on food prices, plant growth, disease and drought resistance.

Biochar
Biochar is charcoal produced by 'cooking' plants or manure with little or no oxygen. It is decay-resistant and can store carbon in soil for thousands of years. Useful on a small scale, but growing biochar crops conflicts with the demand for food and biofuel production.

Volcano balloons
Hosepipes attached to giant helium balloons would spray particles high into Earth's atmosphere to mimic the cooling effect of volcanic eruptions. For example, aerosols released by the 1991 Mount Pinatubo eruption cooled global temperatures by an average 0.5°C (0.9°F). The proposed balloons would be the largest and tallest man-made structures in history.

Reforestation
Regrowing trees in previously forested areas to increase the carbon dioxide they absorb is cheap and safe, but conflicts with the ever-rising demand for agricultural land for food and energy production.

1 Helium balloon
A helium balloon the size of a football stadium is attached to a hosepipe and tethered to a ship.

2 Tethered pipe
The hosepipe pumps particles to 25km (16mi) above Earth's surface – double the cruising height of your average commercial airliner.

technology hasn't been developed to intervene on a planetary scale," notes Andy Parker.

Still, there are a few examples of outdoor field tests. The SPICE project included a plan, later abandoned, to pump water one kilometre (0.6 miles) vertically through a pipe attached to a helium balloon. Its aim was to test the feasibility of squirting sulphate aerosols through a giant hosepipe 20 kilometres (12 miles) above the ground. "We don't know if it's technically possible," continues Dr Hunt. "No one has built a 20-kilometre (12-mile) pipe that goes vertically upwards." Among his unanswered questions are, firstly, can we build and launch a balloon big enough, and secondly, can we build a pipe strong enough?

Other geoengineering proposals rely on pre-existing technology. Fertilising oceans with iron, for example, has already happened on a small scale although not necessarily legally. It needs lots of tanker ships, chemical plants and iron. "There's nothing technically difficult about that," says Professor Andy Ridgwell from Bristol University.

It would take hundreds of years to see results from iron fertilisation and other CDR technologies though. They rely on slow natural processes, such as fertilising tiny marine plants that transport carbon into the deep ocean when they die. "You can't suddenly pull loads of

KEY DATES

MAN-MADE WEATHER

1891 Rainmaker Robert Dyrenforth tries proving noise causes downpours by exploding dynamite kites over Texas.

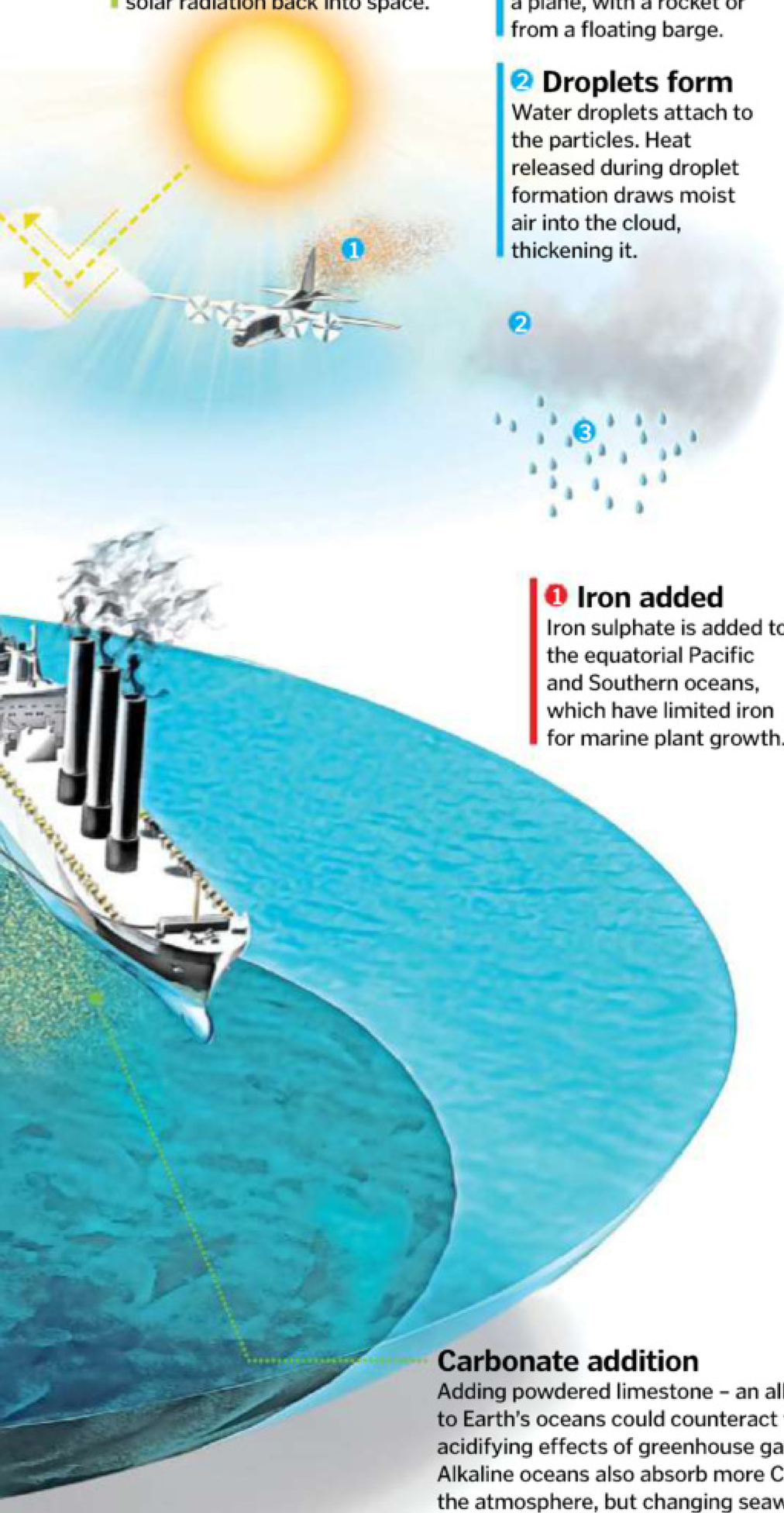
1946 Vincent Schaefer performs the first cloud-seeding experiments, dropping dry ice pellets into clouds.

1952 34 die in a flood in Lynmouth, England. The UK cloud-seeding Operation Cumulus is blamed.

1967 Operation Popeye, a secret US cloud-seeding project, seeks to deluge enemy troops in Vietnam.

2008 The Chinese government tries to prevent rain at the 2008 Beijing Olympics by launching 1,104 rockets.

DID YOU KNOW? *Global temperatures could rise by more than 1°C by the end of this century, even if we reduce carbon emissions*



Cloud seeding

Cloud seeding is a technique for man-made rainmaking already used around the world to varying degrees of success. Rainfall naturally occurs when water droplets attach to sand, dust or salt particles. Cloud seeding squirts extra particles into clouds to spawn new raindrops. Salt is used in warm tropical clouds, while silver iodide is added to cold clouds to create extra ice crystals.

Some scientists believe cloud seeding can brighten clouds to counteract climate warming too. The extra particles make the clouds denser, whiter and more reflective, deflecting more sunlight back into space.

Ocean fertilisation

Marine plant life is at the core of the ocean food chain. The plants are a source of food for other marine life, and happen to take up and bind carbon dioxide as well. They rely on the availability of nutrients to grow – most commonly nitrogen or iron. Fertilising the oceans with iron sulphate is believed to increase their growth and reproduction, which would in turn increase the amount of carbon dioxide they take up, reducing the effect of carbon emissions. Some scientists also believe that the increased marine plant life may increase the number of fish in the sea, in turn improving our food supply.

❷ Microalgae bloom
The rich iron supply creates vast blooms of tiny marine plants, which take up CO_2 as they grow.

❸ Carbon locked away
As the plants die, some fall to the ocean floor, taking locked-up carbon dioxide with them which becomes buried as sedimentary rock.

Can we stop a hurricane?

Hurricane Katrina in 2005 was arguably the worst natural disaster in American history, and many scientists believe hurricanes will only worsen with climate change.

So there's no shortage of ideas for stopping these devastating storms. In 2009, Bill Gates backed a proposal to halt hurricanes by towing tub-like barges into their path. These would cool the warm ocean waters fuelling the storm.

Most plans underestimate a hurricane's power though; according to the NOAA Hurricane Research Division, one storm can release the energy of 10,000 nuclear bombs. For example, to fight a hurricane with water-absorbent powder you'd need hundreds of planes to make sorties every one and a half hours.

Some therefore argue that it's cheaper and more practical to adapt to hurricanes by, for instance, building stronger houses.

The risks of geoengineering

Geoengineering is controversial because it involves large-scale changes to Earth's climate. Critics discuss possible negative side effects, like that ocean fertilisation might cause toxic algal blooms, or that geoengineering gives industry and government excuses not to cut carbon emissions.

Geoengineering also raises issues of ethics. Cooling the climate with sulphate aerosols "is potentially cheap enough for single countries to do", says Professor Andy Ridgwell, Bristol University, but could impact other countries' climates as well.

Others fear 'rogue' geoengineers. For example, an American businessman dumped 100 tons of iron sulphate into the Pacific in July 2012 in an unauthorised ocean fertilisation scheme.

carbon dioxide out of the atmosphere with any of them," explains Professor Ridgwell. "They lend themselves to gradual mitigation."

Growing vast new forests or fast-growing crops competes with existing land uses, explains Dr Tim Lenton from Exeter University. The idea is to repeatedly harvest fast-growing crops like eucalyptus, which capture the carbon dioxide they use to grow. Crops growing on the best soils take up the most carbon, but you want to use those soils to grow food. "The plausibility problem is that you're in potential competition with other land uses in a world where dietary demands are rocketing."

Reflecting sunlight back into space with aerosols is the fastest geoengineering method. It mimics the rapid cooling effect of a large volcanic eruption. "Once you start blocking out some sunlight, temperatures drop quite quickly," explains Andy Parker. For example, in the two years following the eruption of Mount Pinatubo in the Philippines in 1991, global temperatures cooled by about 0.5 degrees Celsius (0.9 degrees Fahrenheit) on average.

So realistically how fast could we cool the planet? Dr Hunt concludes: "Let's suppose the Greenland ice sheet completely melts and we get a one-metre [3.2-foot] sea-level rise. It could be done in five years – if we've got time to think about it, 20-30 years from now."

© Weather Modification, Inc/Christopher Grilliot/Bruce Boe; SPL; Peters & Zabransky; NASA

How to build a mega-aquarium

Dive inside one of the largest aquariums on Earth and discover how we replicate an ocean in a tank

Aquariums, and in particular the awe-inspiring tunnel oceanariums that allow you to walk through marine environments yet stay completely dry, are amazing feats of modern engineering.

First of all, the engineers have to ensure the glass is strong enough to hold back up to 42.8 million litres (11 million gallons) of water. And no, we haven't just plucked that number out of thin air; that's the capacity of the SEA Aquarium in Singapore (see main image).

The SEA's acrylic panel is 36 metres (118 feet) wide, 8.3 metres (27.2 feet) tall and over 70 centimetres (27.6 inches) thick to cope with the immense pressure generated by the huge volume of water. Behind this panel are all manner of marine creatures, from goliath groupers to giant manta rays.

Even after the tanks have been constructed, the water poured in and salinated and the various fish introduced to their respective homes, a lot of upkeep is required. As the tanks are far more contained than the endless oceans, cleaning up waste matter and uneaten food must take place regularly. This is done using one of three common filtration techniques. Mechanical filtration employs filters and pumps to remove waste, fractionation separates the water from particles that have dissolved in it, and finally there is ozone, which kills off harmful bacteria in the water, much like chlorine in swimming pools.

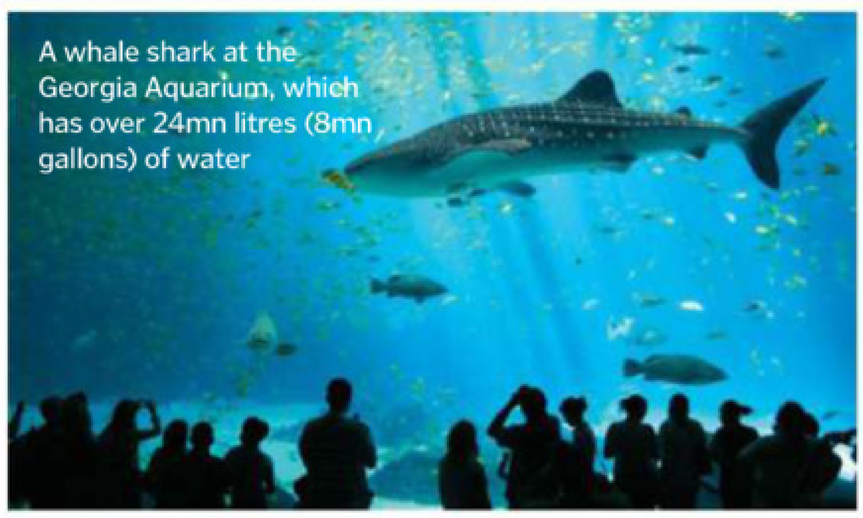
In order to keep the tanks clean for fish and viewers alike, sand filters and skimmers are also incorporated. The sand filters use pumps to blast the water through them and debris is caught by the fine grains, while the protein skimmers pass the water through a valve that injects air into it. This creates lots of tiny bubbles which any debris sticks to.

Clear strength

Aquarium tanks have to meet rigorous safety standards. Often, all that stands between the public and millions of litres of water, sharks and other fish is a single sheet of acrylic. Acrylic has become the standard in aquariums due to its dual qualities of being extremely strong and transparent. The latter quality it, of course, shares with glass, but acrylic's strength really sets it apart.

Acrylic sheets are up to 17 times stronger than glass and have the added advantage of not becoming weakened by prolonged exposure to water. The high molecular weight of cast acrylic sheets makes cutting the panel much easier and the flexible nature of the plastic allows for curved viewing portals without compromising on structural integrity.

Although glass doesn't scratch as easily, acrylic is the way to go for a strong, durable, flexible and transparent material to best show off an aquarium's inhabitants.



A whale shark at the Georgia Aquarium, which has over 24mn litres (8mn gallons) of water

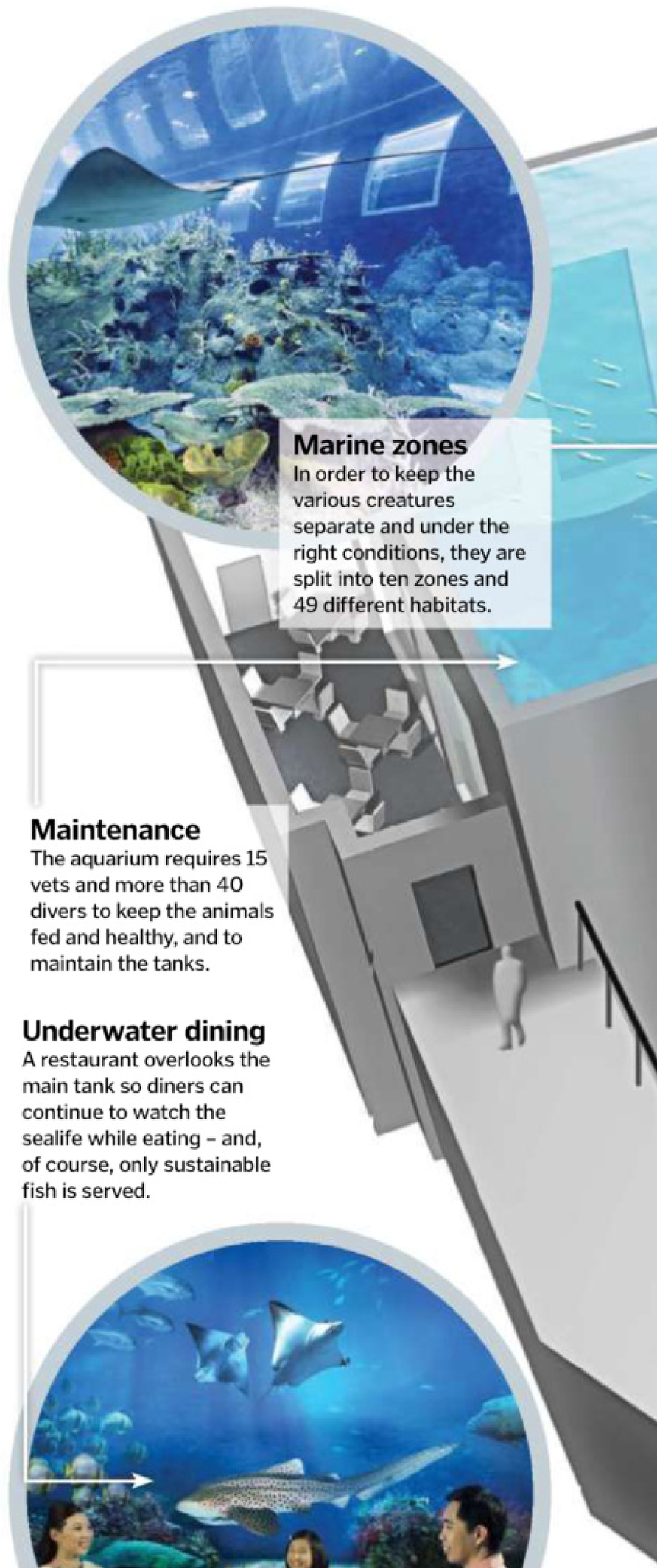
Re-creating marine habitats

Every large aquarium has to deal with the challenge of meeting the needs of the diverse creatures it plays home to. Visitors want to see salt and freshwater fish, plus other creatures, so they have to replicate a variety of environmental conditions. The Ocean Voyager tank in the Georgia Aquarium, USA, poured 680,000 kilograms (1.5 million pounds) of sea salt into its 24-million-litre (6.3-million-gallon) tank. After this initial outlay though, the tank requires very little salt to keep it salinated.

Water temperature is also very important. Depending on the location and inhabitants, temperature varies wildly, so tanks are constantly checked and controlled by thermostats and heaters. For fish that live in deep water, dim lights are used so we can see them without upsetting their natural environment.

Explore the SEA Aquarium

Take a tour of this supersized oceanarium in Singapore



Marine zones
In order to keep the various creatures separate and under the right conditions, they are split into ten zones and 49 different habitats.

Maintenance
The aquarium requires 15 vets and more than 40 divers to keep the animals fed and healthy, and to maintain the tanks.

Underwater dining
A restaurant overlooks the main tank so diners can continue to watch the sealife while eating – and, of course, only sustainable fish is served.

KEY DATES
HISTORY OF AQUARIUMS

50 CE
The Romans are credited with the invention of the aquarium, the first a marble tank holding sea barbel.

1369
Emperor Hongwu of China orders a porcelain company to begin making tubs to hold goldfish.

1846
Anne Thynne is the first known person to create a balanced aquarium, filling it with coral and seaweed.

1853
The first public aquarium opens in London Zoo, with Philip Henry Gosse (right) coining the word 'aquarium'.

1908
The invention of the mechanical air pump heralds a revolution for aquariums as a home hobby.

DID YOU KNOW? *The biggest acrylic panel is in the Hengqin Ocean Kingdom aquarium in China at 8.3 x 39.6m (27.2 x 129.9ft)*

Marine park
The whole site houses 100,000 animals, 800 different species and an incredible 45mn litres (10mn gallons) of water.

Main tank
There are more than 50,000 marine animals swimming in 18mn litres (4.8mn gallons) of water in the main tank alone.

Suites
For those that fancy sleeping with the fishes the SEA Aquarium also has a number of hotel rooms looking out into the main habitat.

Dome
Guests are also able to stand in an enclosed area inside the tank itself to feel fully immersed in the marine environment.

Dimensions
The viewing pane is an incredible 36m (118ft) wide, 8.3m (27.2ft) tall and 70cm (27.6in) thick.

Filters
Dozens of filters hidden in the landscaping are needed to keep the water fresh and clear from food and other waste.

Gallery
The three-tiered viewing gallery allows for up to 300 people to watch the sealife at any given time.

Single panel
The panel is one of the world's largest and is made of acrylic because this material is both stronger and cheaper than glass.

© Resorts World Sentosa; Peters & Zabransky

Exploring a coal mine

Coal fuelled the Industrial Revolution and even today is responsible for 40 per cent of the world's electricity, but how is a colliery laid out?

There are two basic types of coal mines, also known as collieries. The first is the opencast surface mine, which consists of a coal seam covered by an overburden layer of soil and rock. Bulldozers clear the soil and explosives are used to break up the remaining overburden. Draglines and power shovels are then brought in to remove this material, followed by the extraction of the coal. After the mine is exhausted the topsoil is returned to landscape the area.

The second type, the underground mine (shown here), can access deeper seams of coal and is far more dangerous and challenging. Originally, the coal face was dug by pick and shovel, but as time went by, explosives were used to blast away at the coal seam.

Modern mines use machines that have tungsten bits that cut into the coal face. Longwall and room-and-pillar systems are the two main methods for extracting coal. The longwall method slices horizontally into the coal face and drops the mineral onto conveyer belts. The room-and-pillar method cuts a grid-like network of tunnels in the coal seam, leaving the remaining pillars to support the roof. The longwall method can be used to finish off the pillars that are left behind by the room-and-pillar technique.

Fire in the hole!

Coal seams can catch fire and burn for decades or even centuries, either due to accidental causes such as gas explosions or natural causes when there is sufficient heat and ventilation to bring about self-combustion.

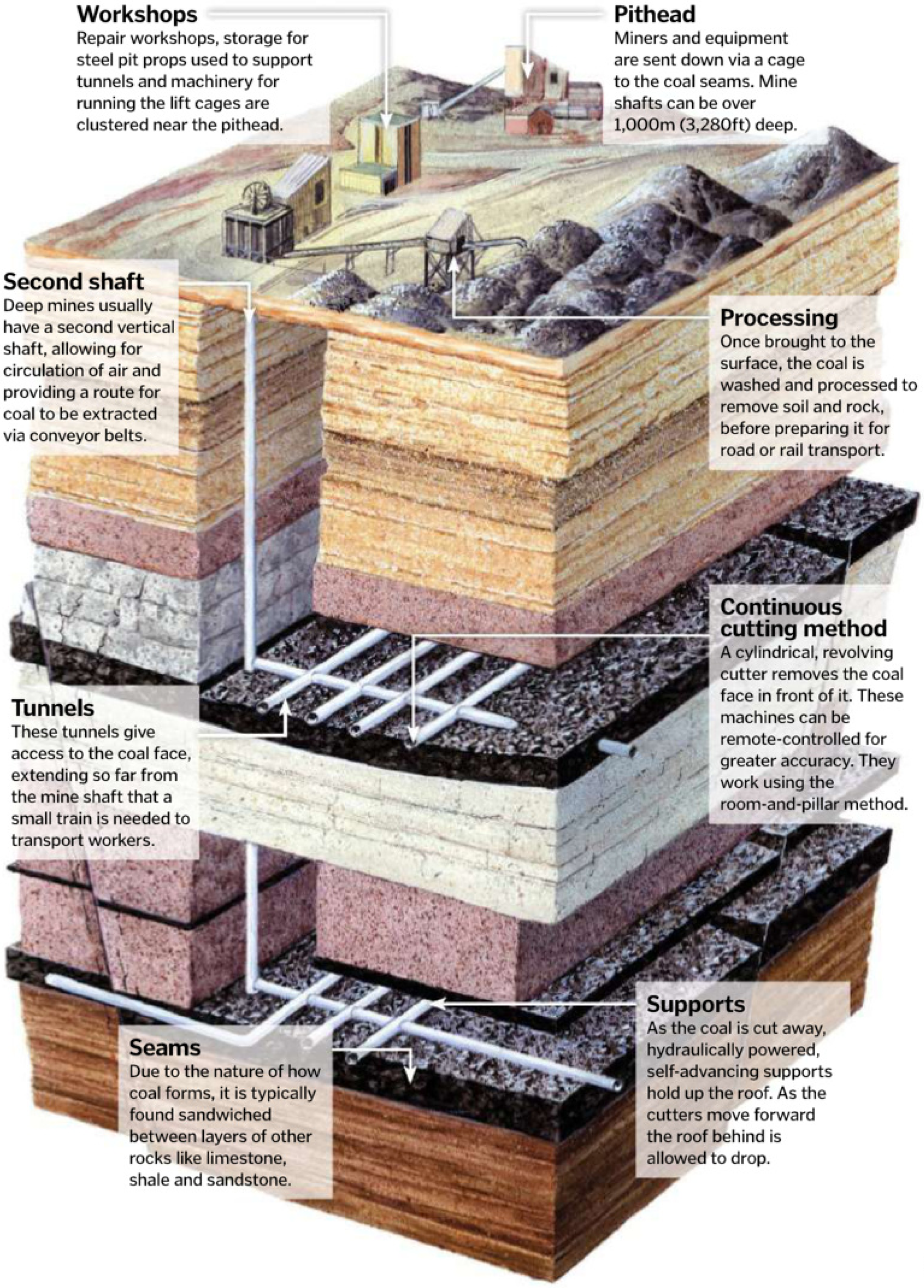
Incredibly thousands of worldwide seam fires account for as much as three per cent of carbon dioxide emissions. They also belch out other toxic gases and cause subsidence and destruction to their local landscapes.

They only stop burning when they exhaust their coal reserves or are extinguished through human intervention. Deep mine fires are put out by isolating them and pumping inert gases around the area of the blaze.

Fires nearer the surface, on the other hand, can be dealt with by pumping mud and water into the ground, followed by covering the area with an impermeable layer of sediments. The extent and depth of many of these fires though means they are impossible to put out.

Coal mine level by level

Take a tour of the main areas that make up a colliery



© SPL

Bomb-disposal suits

How does this armour protect the technicians who disarm explosives?

Bomb-disposal suits are a form of specialised heavy body armour used by weapons specialists when diffusing explosive devices. They are used primarily by the military, but also see action in police forces. Their main role, not surprisingly, is to protect the wearer should the bomb unexpectedly detonate.

The suits are designed to mitigate the effects of intense heat, pressure and fragmentation – the debris from a bomb that flies off at high speed. This protection is achieved by combining several high-strength but low-weight materials such as Kevlar, Nomex, foams and a range of plastic composites, each layered and mixed to provide an all-round barrier to the effects of a blast.

As well as shielding the wearer, these advanced bomb suits are also responsible for keeping them connected to their team and as comfortable as possible. These factors are critical when out in the field, as often conditions can be extreme (such as in hot climates) and bomb disarmament is a very stressful operation. Built-in communication and ventilation systems ensure the technician stays informed and cool under pressure, respectively.

Over the past decade or so bomb-disposal suits have been in increasingly high demand, primarily due to the conflicts in Iraq and Afghanistan. This said, remotely controlled robots are now being used more and more to help avoid human casualties.

The history of disarming bombs

The earliest references to bomb disposal stem from World War II in England. Nazi Germany had undertaken a large bombing campaign against Britain, and a number of the devices that were dropped landed but failed to detonate. This caused a spiked increase in civilian deaths, with unexploded bombs accidentally being triggered during people's day-to-day lives.

This led the British government to begin training volunteer members of the public in bomb-disposal techniques, with groups tasked with clearing sites laden with buried and undetonated weapons. Unlike bomb-disposal units today, these civilians wore no protective clothing and had only very basic tools, having to make do with spades, axes and wire cutters.

Anatomy of the ABS

From head to toe, the materials and tools of the Advanced Bomb Suit explained

Helmet
The ABS's helmet is made from lightweight but high-strength fibre and weighs only 3.6kg (7.9lb). The visor is constructed from laminated acrylic and polycarbonate.

Comms system
The helmet is also equipped with a MIL-SPEC communications system, consisting of a microphone and set of speakers. It is powered by an internal battery pack that can last for about five hours.

Raised collar
As an explosion can cause differential acceleration between the head and torso, each ABS is equipped with an articulated spine protector and supportive neck collar.

Cooling system
Due to the multiple thick layers, a Nomex body suit with a woven capillary tube network is worn next to the skin. This is connected to a 2l (0.5ga) water reservoir that pumps ice-cold water around the ABS.

Ballistic panels
Composite ballistic panels are fitted to the outside of the suit in order to prevent bomb fragments entering at high speeds.

Lung overpressure deflector
Special rigid ballistic panels are placed over the chest. These offset panels are designed to absorb the high pressure generated on detonation, countering lung compression.

Materials
The suit is made from a mix of flame-retardant Nomex and Kevlar layers. These specialise in protecting the wearer from the intense heat generated in a blast.

© Alamy

A furnace in action – temperatures inside the bowl can reach a fiery 1,650°C (3,000°F)

The tapped out molten steel cools in a ladle, but it's a race against time to use it before it cools too much

The molten steel is made into billets, which are huge rods of steel. They go from glowing red hot to grey in a matter of minutes

THE STATS
CELSA STEEL MILL

DAILY SCREENING 1,000 tons
MAXIMUM TEMP 1,650°C
YEARLY OUTPUT 1mn tons
FURNACE VOLTAGE 275v
ELECTRODE COST £4,000
SLAG PRODUCTION 18,000kg

DID YOU KNOW? *Up until February 2014, China produced more crude steel than the rest of the world combined!*

HIW writer Jamie gets shown around the control room where everything at the plant is carefully monitored

Making steel

A behind-the-scenes visit to one of the biggest steelworks in Britain reveals how this essential metal is made

Steel is everywhere. Found in bridges, trains, computers and even your cutlery drawer, this alloy is one of the most widely used materials in the world. It is full of properties that make it the go-to choice for the construction of some of the world's most incredible structures, while being adaptable enough to be used for car doors and teaspoons, but how is this amazing construction product constructed itself? To answer this we went to the CELSA Steelworks in Cardiff, Wales, to get to grips with the process of creating steel.

Essentially, there are two main methods of making steel today. One is called basic oxygen steelmaking (BOS), which is how 60 per cent of the world's steel is currently produced. To begin this involves extracting iron ore from rocks in the ground. Next comes a process called smelting. Steelworkers fill a blast furnace with the iron ore, charcoal and limestone, pump vast amounts of air into the bottom – fuelling the fire that was created when an electrical charge was put through the system; this melts the iron down, allowing workers to 'tap' it out of the furnace. Pumping oxygen through the liquid iron oxidises the carbon content and, when it reduces to a certain level, steel is born.

The second process is called electric arc furnace (EAF), which instead of raw materials uses scrap steel to create new metal. It is this latter process which is employed at Cardiff's CELSA steelworks, all overseen by Ron Davidge, who has worked for several years in the steelmaking industry – first in the melt shop and then the control room.

"The EAF process starts in the scrapyard," Davidge tells us. "We put the scrap metal into the screening process and that separates the good steel from the rubbish. It's then loaded into the baskets and brought into the melt shop. We have different metal ratios based on the grade of steel we're making. The best steel has a copper content of around 20 per cent. Much more and the steel is weakened, as copper wire has a habit of breaking up under pressure."

The melt shop is the vast open building in which the really exciting part of steelmaking occurs – home to the furnace fire.

With a wrenching and a scraping, the lid is lifted off the furnace and the huge basket full of pieces of scrap metal is tipped into the furnace. Lifted up with the lid are three immense graphite electrodes, which are glowing red-hot.

"We have to keep the furnace at an incredibly hot temperature", explains Davidge, "because if we let it cool down it takes a huge amount of energy and time to reheat and we don't want to waste either of those. After we tip in the metal, the electrodes get lowered and we put an electrical charge through them that is conducted by the scrap. The electrodes have an angled base to increase their surface area."

When it is time for the second bucket of scrap to be lowered into the furnace, which we're told is currently running at around 1,650 degrees Celsius (3,000 degrees Fahrenheit), the lid is

raised and an incredible ball of flame billows out of the container. The scrap is released into the pit where it is rapidly melted down into the liquid steel bath.

"The walls of the furnace are lined with silica brick, which has a very high melting rate. Even so, the shelf life of even good-quality brick only lasts about three weeks before it needs to be changed. We have to make sure we protect our furnace because they're expensive", says Davidge. "The furnace is also lined with manganese and slag from previous meltings to provide some extra protection."

It is at this point in the process that the BOS and EAF steelmaking methods converge and follow the same path (see diagram, right).

Once the majority of the steel has been melted down, a burst of oxygen is sent through the steel oxidising the contents until most of the impurities are removed and the perfect level of carbon content is reached.

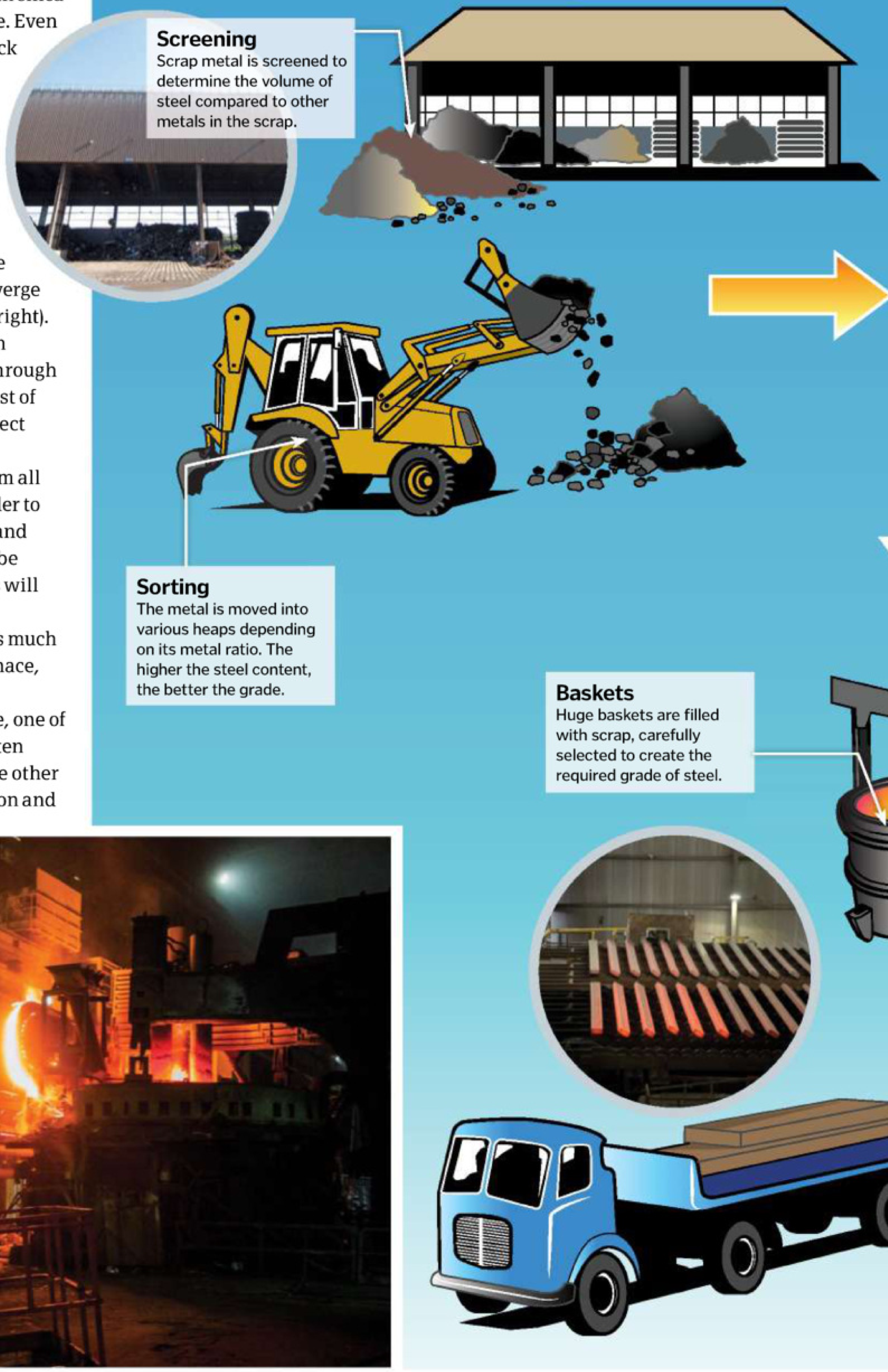
Slag is the thick substance created from all the waste products in the process. In order to remove this, the furnace is tipped back and forth a few times, allowing the waste to be pushed out of the slag door. This process will often lose a bit of liquid steel but it is an acceptable sacrifice at this stage. After as much slag as possible is removed from the furnace, the tapping process can begin.

There are two pipes below the furnace, one of which allows a stream of 145 tons of molten steel to run down it into a bath, while the other contains metals and alloys, such as silicon and

The temperature on the melt shop floor becomes almost unbearably hot as the furnace roars into action

Steel step-by-step

Two routes to making steel explained



6,000M³

BIGGEST FURNACE ON EARTH

The largest furnace in the world is Furnace 1 at the Gwangyang Steelworks in South Korea. It has a giant capacity of 6,000 cubic metres (212,000 cubic feet).

DID YOU KNOW? *There are more than 3,500 grades of steel, 75 per cent of which have been developed in the last 20 years*

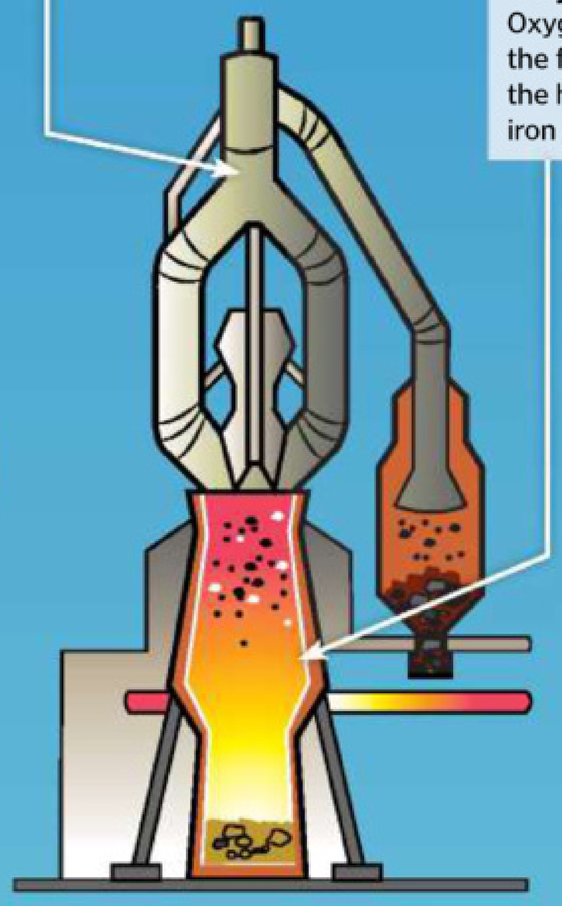
Basic oxygen steelmaking

Blast furnace
Raw iron ore is melted down in the blast furnace, with as much slag filtered to the secondary chamber as possible.

Oxygen
Oxygen is pumped into the furnace to raise the heat and melt the iron and scrap steel.

Treating
The iron ore is treated to remove unwanted elements like sulphur.

Extraction
Iron ore is extracted from rocks. This serves as the raw ingredient for steel.



Melting
An electrical charge is put through the electrodes, conducted by the metal, which rapidly heats up and begins to melt.

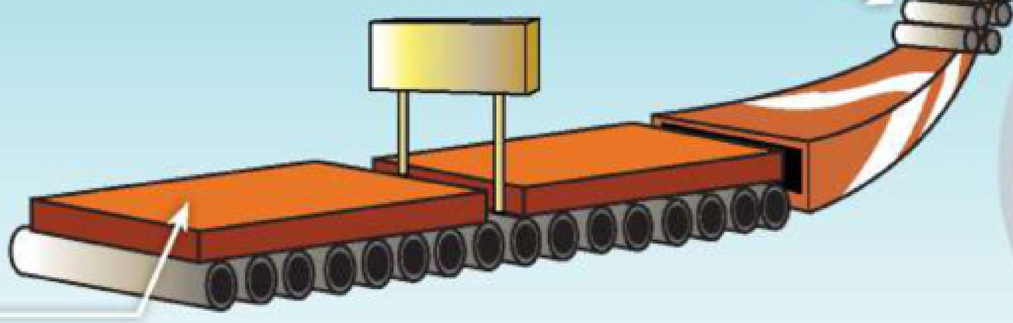
Tapping
Slag is removed by tipping the furnace back and forth before liquid steel is 'tapped out' via pipes.

Roof and electrodes
The roof of the furnace is removed and electrodes raised. The furnace is 1,650°C (3,000°F).

Metal deposited
The bottom of the basket opens, tipping the metal in. The roof and electrodes are lowered.

Crane
A powerful crane picks up the basket and carries it over to the furnace.

Pouring steel
Liquid steel is poured into six tubes, which vibrate and are angled to ensure a smooth, steady flow.



Cutting
The cooling metal is cut into billets, which then get transported to the rod and bar mill for shaping.

manganese, which will be poured into the molten metal mixture to create the right grade of steel for that particular batch.

The bath is analysed and more tweaks are made to the constitution of the steel before it is left to cool slightly, developing a dark, bubbling surface skin, looking a bit like a slightly over-grilled cheese sandwich.

The next stage is to turn that molten steel into steel bars and rods. This is done by craning the container up onto a huge rotor arm, which holds one full bath in waiting and another over a trough. This trough has six exit points, through which the molten metal flows. In order to keep it flowing evenly, the trough vibrates slightly, which keeps the liquid metal constantly moving. The exit points are copper pipes, which drop at a slight angle before levelling out to a horizontal half-pipe, much like a kamikaze water slide.

"As well as the vibrating pipes, the angled drop is designed to keep the stream consistent and smooth," Davidge says. "Too sharp a drop and cracks could appear, too shallow a drop and the metal will be too cool for it to be cut."

The constant flow pushes the molten metal along the line, where it cools surprisingly rapidly. Mechanical cutters are set up, again at a slight angle so it can cut the metal in a straight line as it continues to move in a process called

The tapping of the molten steel is an incredible sight. Extra elements like silicon are added at this stage to create the right grade of steel

How do we make steel stainless?

Steel can be made stainless by the adding of at least 10.5 per cent chromium to the melt. When cooled, the chromium protects the steel from rusting by providing an oxide layer on the surface to protect the steel. As the chromium has very low levels of reactivity, it doesn't rust, keeping your cutlery shining for years.

The origins of stainless steel are fairly complicated. As far back as 1821, scientists noticed that alloys of chromium and iron were resistant to rust, but it wasn't until 1913 that the practice took off. Sheffield's Harry Brearley, looking to create rifle barrels that didn't corrode, discovered that steel-chromium alloys with at least six per cent chromium didn't oxidise. Further studies led him to create a steel product with 12.8 per cent chromium, which is widely considered the first genuine stainless steel.

A brief history of steel...

800 BCE
The Iron Age begins. It follows the Bronze Age and heralds the start of iron as the main metal for making tools and weapons.

206 BCE
During the Han Dynasty, Chinese metalworkers produce an early form of heat-treated steel, as well as high-carbon cast iron.

1692
The first recorded creation of steel in Sheffield. It is called blister steel and is formed by using charcoal to melt wrought iron and increase the carbon content to create steel.

1708
A cast iron foundry is established in Shropshire that uses coke, a substance created by heating coal, to make cast iron – free from impurities caused by charcoal and coal.

1751
The crucible method of creating steel is developed in Sheffield, in which steel is melted in a crucible to separate slag, which can then be removed.

DID YOU KNOW? *William Kelly, the inventor of modern steelmaking, had to sell his patent to Henry Bessemer due to bankruptcy*

Many workers at the plant have been at the site for decades. One slip-up could ruin an entire day's production

continuous casting. The swiftly cooling billets turn from red to grey in front of our eyes, before being stacked on the back of a huge lorry to be transported to the rod and bar mill where they will be shaped.

The whole process takes around 45 minutes from the moment the first basket of steel is deposited in the furnace to the point at which the container has finished emptying its load of molten steel into the trough.

Any delay would lead to the entire process becoming much less efficient, whether it's the furnace being underused, the molten metal cooling too much and needing reheating or the billet stream grinding to a halt. The plant tends to work 24 hours a day, seven days a week, with maintenance being done in brief periods of downtime or scheduled shutdowns.

We continue outside to take a quick look around the 'slag shed', where all the waste material is deposited. However, this will not get thrown away as the slag can be sold on to companies as a road-building product.

Inside a steelworks is hot, noisy and dusty (they create 50 tons of dust every day) and the pressure to get things right is immense as one slip-up can compromise an entire day's work. Steel is pretty big business and to experience the raw power of that furnace and the dedication of the workers to ensure hundreds of tons of top-quality steel gets produced every day was incredible.

Steel, in its many forms, is a vital material in today's society and its strength, durability and flexibility is only mirrored by the people and the process that creates it.

ON THE MAP

Biggest steel producers by continent

1 China: 62mn tons
2 USA: 6.8mn tons
3 Germany: 3.6mn tons
4 Brazil: 2.6mn tons
5 South Africa: 0.5mn tons
6 Australia: 0.4mn tons

Source: World Steel, Feb 2014

Iconic steel structures

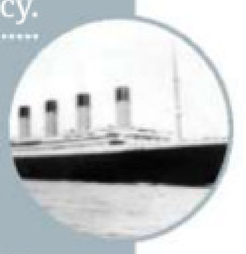
1 Sydney Harbour Bridge

One of the most iconic structures in the world, the Sydney Harbour Bridge spans 1,149m (3,770ft) with the signature arch stretching 503m (1,650ft). The steelwork weighs 52,800 tons and is made of a special steel blend containing Pearlite, which bumped up the carbon content and in doing so increased the strength to 1.3 times that of normal steel.

2 Willis Tower (formerly Sears Tower)

Completed in 1974, the Sears Tower overtook the Empire State Building as the USA's largest steel building, standing 442m (1,450ft) high. It made use of Khan's Bundled Tube principle, which involves a number of steel pipes secured together to create a rigid superstructure that maximises the steel used for efficiency.

3 RMS Titanic



A 2008 study suggested the steel that went into making this 46,000-ton ship could have aided its downfall. As steelmaking was still in its infancy, the ship's metal was ten times as brittle as modern steel, due to open hearth furnaces allowing sulphur, oxygen and phosphorus to infiltrate the metal.

1784 The puddling furnace is developed by Englishman Henry Cort, which decreases carbon content in iron by stirring.

1856 William Kelly and Henry Bessemer discover blowing oxygen through iron creates an efficient way of making steel and they patent this idea.

1876 Sidney Gilchrist Thomas adds limestone to the mixture to remove phosphorus, which makes steel brittle.

1913 Harry Brearley creates stainless steel by mixing chromium in with the steel mixture to form a corrosive-resistant layer.

2003 A patent was filed by Morris Dilmore and James D Ruhlman for Eglin steel, a very strong steel blend with low to medium carbon content. This is thought to be the strongest steel in the world.

© Peters & Zabransky

Inside battle simulators

A revolutionary new system for training the soldiers of tomorrow

Training recruits to use some of the world's most expensive and complicated military technology is no easy task. Millions of pounds' worth of military hardware needs to be placed in the hands of learners and, while these future fighters are carefully managed, the run-time costs to operate trial mission after trial mission are quite simply astronomical.

After years of development, defence company BAE has created a virtual battle training system – a simulation network that runs through live scenarios with several players simultaneously. Indeed, thanks to the Dedicated Engineering Network (DEN), simulators controlling virtual Type 45 destroyers, Typhoon fighter jets and even E-3D Sentry aircraft can be brought together in a simulated combat environment and put through their paces in a range of scenarios combining land, sea and air tech.

In doing this, not only can the most advanced military hardware be tested together as one functioning unit, but trainees and professionals alike can run through missions without even having to set foot outside.

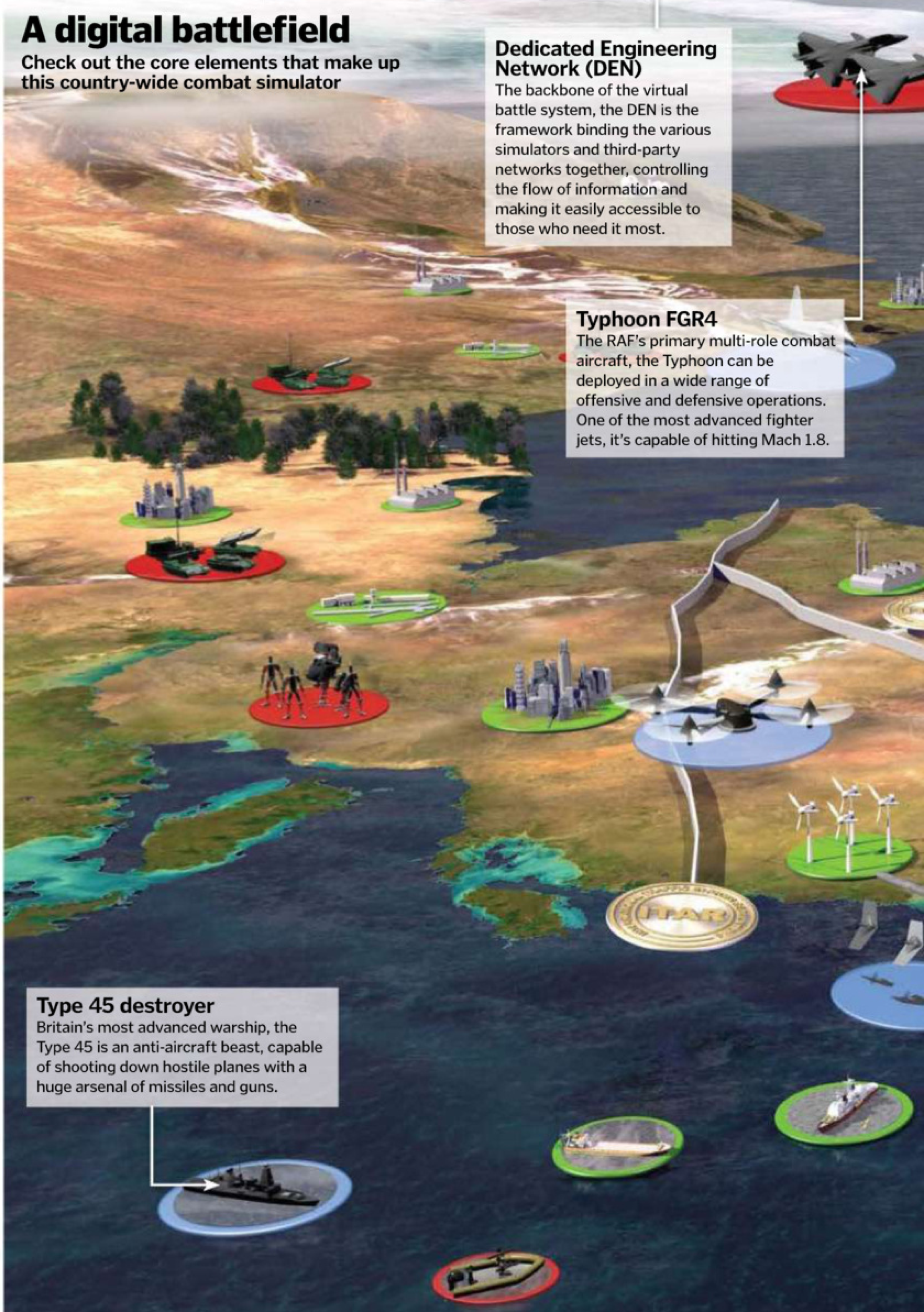
This not only saves money but also allows for a greater range of scenarios to be played out in a short period of time. Further, thanks to DEN securely managing integration with Ministry of Defence (MoD) networks, scenarios can be witnessed by commanders and decision-makers remotely, granting an unprecedented access to information.

The system is still under testing, with a simulator at BAE's Warton facility in Lancashire, UK, emulating four Typhoons, partnered with two other simulators at different sites which emulate an E-3D Sentry AEW1 and a Type 45 destroyer. With a high level of success to date, more trials are already planned over the next 18 months, with more simulated combat vehicles looking to be integrated – the most notable being the state-of-the-art F-35 Lightning II fighter jet.

Engineers at Apex, BAE's systems integration and experimentation facility based in New Malden, UK

A digital battlefield

Check out the core elements that make up this country-wide combat simulator



Dedicated Engineering Network (DEN)

The backbone of the virtual battle system, the DEN is the framework binding the various simulators and third-party networks together, controlling the flow of information and making it easily accessible to those who need it most.

Typhoon FGR4

The RAF's primary multi-role combat aircraft, the Typhoon can be deployed in a wide range of offensive and defensive operations. One of the most advanced fighter jets, it's capable of hitting Mach 1.8.

Type 45 destroyer

Britain's most advanced warship, the Type 45 is an anti-aircraft beast, capable of shooting down hostile planes with a huge arsenal of missiles and guns.

JMNIAN network
BAE's virtual battle system will be interoperable with the MoD's Joint Multi-National Interoperability Assurance Network (JMNIAN), which provides a hub for all of the armed forces. The DEN simulator can be accessed from numerous bases and defence facilities.

Two of the advanced military vehicles that soldiers can play out battle scenarios with using DEN

1 New Malden facility
The E-3D Sentry is simulated on its own at BAE's New Malden site in London, linked to the simulated environment by BAE's DEN.

2 Warton facility
Four virtual Typhoons are simulated from BAE's facility in Lancashire and link in to the battle system.

3 Broad Oak facility
The simulator for the system's Type 45 destroyer is located at BAE's Broad Oak facility, near the famous Portsmouth dockyard.

E-3D Sentry AEW1
The E-3D Sentry is an airborne surveillance and command-and-control aircraft that specialises in reconnaissance and target acquisition.

F-35 Lightning II
While currently not supported by DEN, over the next 18 months BAE is hoping to integrate support for the F-35, the fighter jet set to become the showpiece of the RAF's military fleet in the next 20 years.

A virtual rival
Facing up against BAE Systems' DEN in the battle for virtual combat training supremacy is American defence contractor Lockheed Martin's Multi-Function Training Aid (MFTA). The MFTA is pitched as being a reconfigurable platform for a wide range of military vehicles, with the system capable of simulating fixed-wing multi-crew aircraft, helicopters, landing hovercrafts, fast attack boats, trucks and even utility vehicles.

The system is based on Lockheed's own Prepar3D simulation software, with a comprehensive suite of simulated controls, multitouch glass panels and authentic cockpit layouts (pictured below) allowing the user to adapt quickly to their specific training vehicle. Data for the system comes courtesy of the WGS-84 database, allowing things like traffic, weather and other factors to be realistically replicated. Throw in extras like a built-in motion platform, electro-optical, infrared and radar sensors as well as real heads-up displays and it's obvious that the MFTA offers new soldiers a valuable insight into life on the battlefield.

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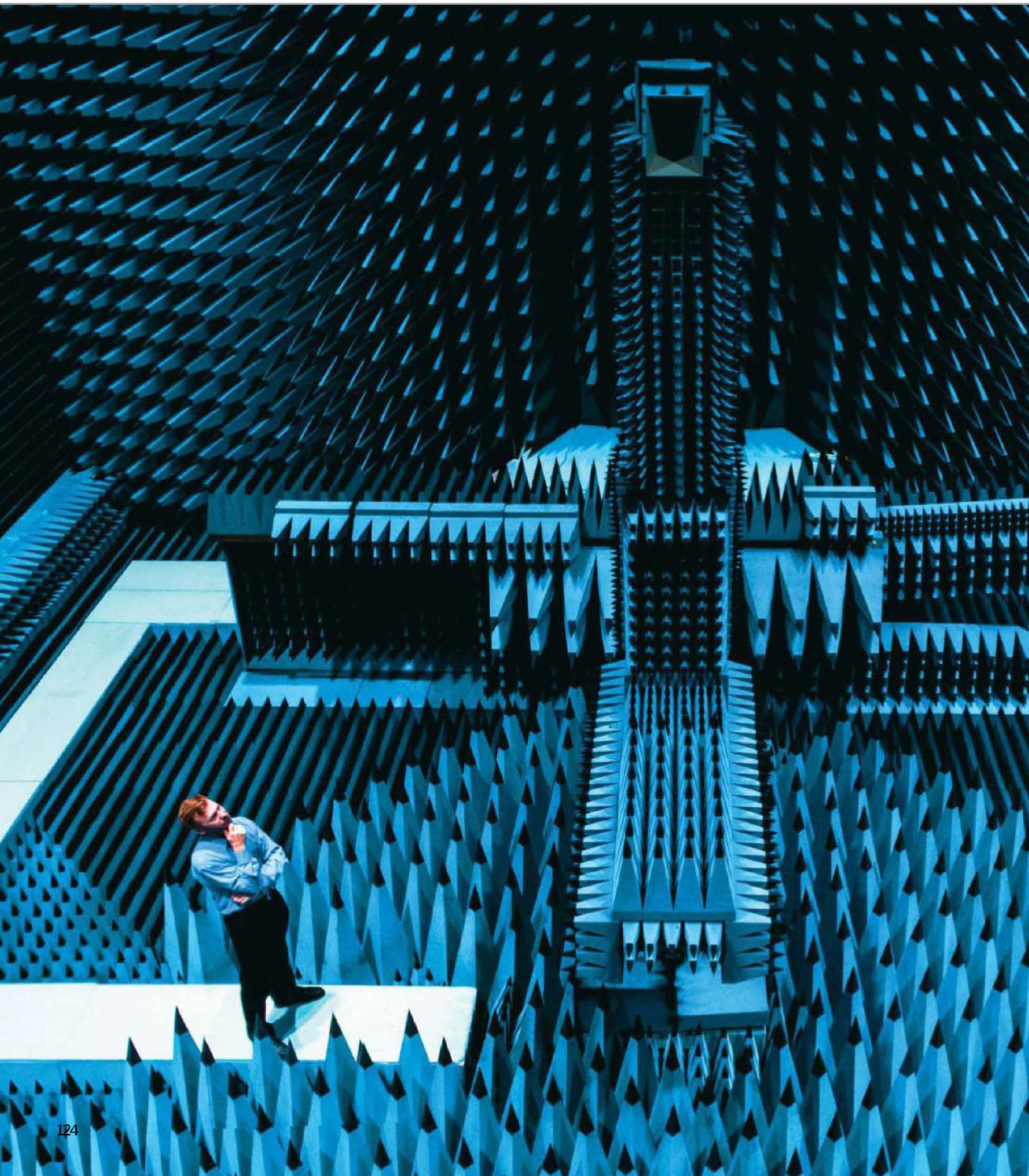
Silent rooms



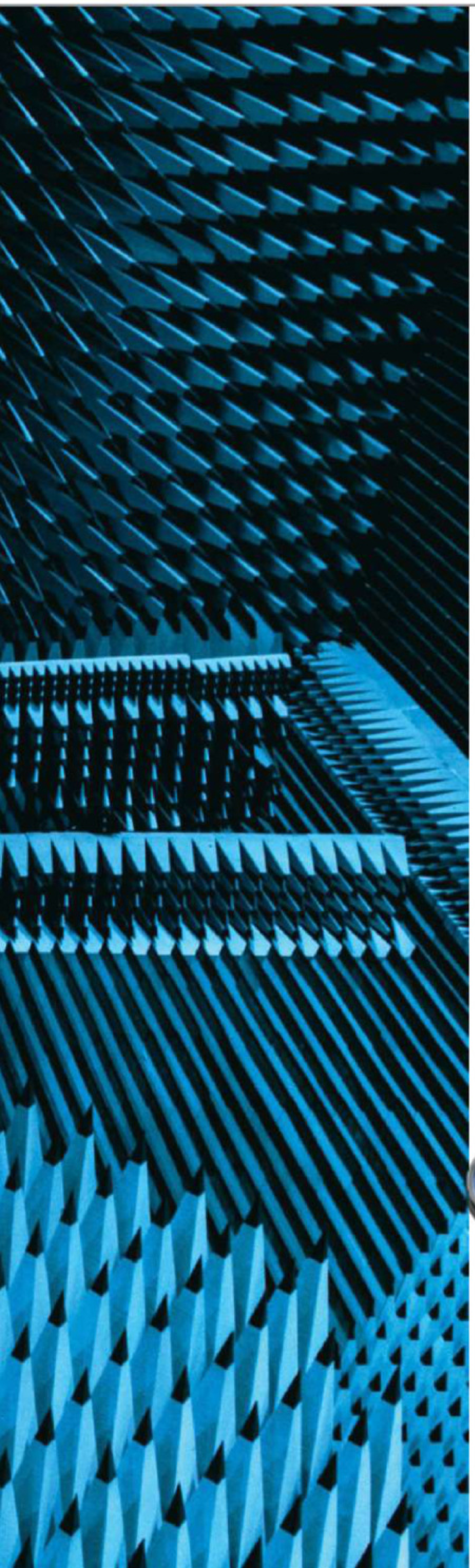
RECORD BREAKERS
VERY HUSH-HUSH

99.99%

MOST SOUNDPROOF ROOM

The anechoic test chamber at Orfield Laboratories in Minneapolis, USA, is so quiet it can induce hallucinations. It absorbs 99.99 per cent of sound. The longest anyone has spent inside is 45 minutes.

DID YOU KNOW? *The opposite is a reverberation room where hard, smooth, reflective walls intentionally bounce sound waves*



The quietest rooms on Earth

How do the walls in an anechoic chamber dissipate sound waves so all you hear is your own heartbeat?

Anechoic chambers are echoless rooms, designed to prevent the reflection of sound waves, but can work just as well at stopping electromagnetic radiation in its tracks. This enables accurate testing of acoustics and electrical equipment without interference from echoes.

To prevent the rebounding of audible sounds, anechoic chambers are lined with fibreglass wedges, covering the walls, floor and ceiling to create an uneven surface. Sound wave energy is absorbed by the fibreglass and transferred into the body of the wedge, where it dissipates. Any reflected sound bounces off at an angle and hits an adjacent wedge, eliminating echo.

Anechoic chambers can also prevent the reflection of electromagnetic radiation, including radio waves, and are used to test antennas and radar. These waves can't be absorbed by pure insulators or conductors, as they're ineffective at accepting energy. Therefore, the material lining radio anechoic chambers is designed to mix the properties of both insulators and conductors.

Rubberised insulating foam is impregnated with conductible metal, such as iron, and formed into mini pyramids. These capture and divert the electromagnetic waves, preventing them from reflecting back into the room. The pyramids' length is designed to match the frequency of the electromagnetic waves being tested, with longer pyramids for low frequencies and shorter ones for high frequencies.

Anechoic chambers are not just free from echoes, but often soundproof as well, and may be encased in concrete or suspended on shock absorbers to prevent noise entering from the outside. The same is true of radio anechoic chambers, which are protected from external sources of electromagnetic radiation by a Faraday cage – a mesh of conducting material that diverts any incoming electrical activity around the room without letting it in.

The history of echoless rooms

First developed in the United States back in the Forties, wedge-lined anechoic chambers were originally used for acoustic testing, housed in concrete structures for soundproofing.

Modern chambers are similar in many ways, but the design has been refined to achieve more efficient loss of audible vibration, particularly at lower frequencies. They are also better insulated from external sources of interference, and are often mounted on sprung floors. This technique is also used in concert halls to protect them from any vibration in the building.

Radio anechoic chambers were developed in the Sixties and used the same principles to dissipate energy. To ensure that there are no unwanted emissions or reflections of electromagnetic radiation in the chamber, all equipment is insulated in nonconducting materials.

ON THE MAP

Anechoic chambers around the world

1 Orfield Laboratories, Minnesota, USA
2 Benefield Anechoic Facility, California, USA
3 The University of Auckland, New Zealand
4 Compact Payload Test Range, Noordwijk, the Netherlands
5 The University of Salford, UK

© SPL

Building Demolition

What goes up must come down – but how exactly do we recycle giant buildings?

An excited hush falls across the deserted tower block. Neighbouring residents look on as the police helicopter overhead double-checks that the exclusion zone is clear. The countdown reaches zero and the button is pushed. An explosive shockwave ripples through 1,500 separate charges, shattering the supporting concrete columns. With surprising grace, the huge 24-storey tower block folds downwards into a billowing skirt of dust.

The mere seconds it takes for the building to come crashing down might be the only part that makes the local evening news, but the real work can extend for months before and after the big bang. Mark Coleman is the managing director of Coleman & Company – one of the UK's leading demolition firms. In an exclusive interview, he talks us through the key stages in the high-rise demolition process.

The first four or five months are spent planning, he explains: "The Health and Safety Executive, the local council… the people who are being evacuated, the firearms and explosives division of the police: you've got to convince these people that you are competent. You have a structural engineer to ensure that up to the point of pressing the button, the building will stand up; an explosives engineer to make sure that at the point of pressing the button, the building will fall down, and that it will fall down at the right place, not spread too far and not damage anything."

Work begins by stripping the building completely. Specialist contractors remove toxic materials, such as asbestos. Furniture, fitted cabinets, electrical wiring, plumbing, flooring and even the windows and plasterboard panels are all taken out as well. In fact, Coleman & Company aims to recycle as much as 98 per cent of a building during the demolition process, and it's much easier to do that *before* it is reduced to rubble. "We don't even throw settees in the skip any more," says Coleman. "We take the fabric off and that gets shredded, we strip the wood, that gets recycled and any metal in there goes into the scrap metal skip."

Once the building has been reduced to a concrete shell, the next six to eight weeks are

5 TOP FACTS
EXPLOSIVE TYPES

Dynamite
1 Invented by Alfred Nobel, dynamite consists of unstable nitroglycerine mixed with fine clay to make it safer. It needs careful handling, and isn't used for demolition anymore.

PETN
2 Pentaerythritol tetranitrate is chemically similar to nitroglycerine and is one of the ingredients of Semtex. In demolition, PETN is used as the detonating cord core.

TNT
3 Trinitrotoluene is a stable high explosive used in demolition. It needs another more sensitive explosive to set it off, and can be melted and poured into moulds without detonating it.

RDX
4 Also known as hexogen, RDX is even more powerful than TNT. It is used as a cutting charge in demolition to sever stronger structural steel beams.

Tovex
5 This water-gel explosive which includes ammonium nitrate has replaced dynamite in many cases – mainly because it's less toxic and is generally safer to use and transport.

DID YOU KNOW? *Police helicopters use thermal-imaging cameras on demolition days to look for anyone still in the building*

High-stakes demolition

When it was built in 1908, the headquarters of the Singer sewing machine company in Manhattan, New York, was the tallest building in the world. When it was demolished in 1968, it was the tallest building ever to be torn down. If you don't count the terrorist destruction of the World Trade Center in 2001, it still is. Since Lower Manhattan is so crowded, explosive demolition was out of the question in this case. Instead, the 47-storey building was demolished the same way it was built – with a crane on the top and crews of workers who dismantled it floor by floor.

Types of demolition

We weigh up the pros and cons of three deconstruction methods (1 = low/5 = high)

Machines

Noise	5
Risk level	4
Disruption	5
Total time	3
Expense	3

Explosives

Noise	3
Risk level	5
Disruption	3
Total time	4
Expense	4

Hydraulic jacks

Noise	1
Risk level	2
Disruption	2
Total time	2
Expense	5

Jets of water are often blasted at buildings during demolition to reduce dust levels

spent 'pre-weakening' the structure. "This does two things," Coleman continues. "One, it allows you to get access [for the explosive charges], but two, it also allows you to use fewer explosives to collapse it. Typically, you remove 1.5-metre (4.9-foot) rectangular arches out of a wall and then try to demolish the next two to three metres of concrete by the use of explosives. BS5607, which is the British Standards code for the Safe Use of Explosives, says you need to minimise the amount you use, so you're not blasting the hell out of it and sending concrete flying all over the place."

The type of explosive used depends very much on the building. A tower block is a relatively weak structure, held up by simple reinforced concrete pillars. These can be destroyed using detonating cord. This resembles coaxial TV aerial cable, but the core is filled with PETN (pentaerythritol tetranitrate) high explosive. This 'det cord' is used as a high-speed fuse for large jobs; it burns at about 7.2 kilometres (4.5 miles) per second, but for tower blocks it has enough explosive power to get the job done by itself. "When you start moving into bigger, more industrial structures – eg power stations and heavy concrete or steelwork – it's a different ball game altogether," explains Coleman. "You are now into shaped, cutting charges. You use these to induce failure in the already pre-weakened section – to blast out the remaining piece that's holding the whole thing together."

While the drilling and pre-weakening is going on, arrangements have to be made for the nearby residents. "Typically on an inner city site, you can be evacuating a few hundred properties and catering for a few thousand

Demolition machines

1 Wrecking ball
A steel ball weighing up to 5,400 kilograms (12,000 pounds) is swung from a long chain. At one time the most common demolition machine, the wrecking ball is used much less now because it has a shorter reach than modern excavators.

2 High-reach excavator
A variant of the JCBs used to dig ditches, the high-reach excavator has a much longer boom arm and a wide base to provide a stable platform. The tallest excavators can reach 67 metres (220 feet) – about 23 storeys – and weigh 200 tons.

3 Concrete pulveriser
The concrete pulveriser is a huge hydraulic hammer. They can weigh as much as six tons, and are used to break up thick foundation slabs and chisel away at stubborn concrete pillars.

4 Shears
This attachment chews up walls and beams using powerful jaws. Large ones can open up to 1.2 metres (four feet) wide and weigh over four tons. Their bite force is 145 tons – about 40 times as much as a Tyrannosaurus rex!

5 Brokk robot
Where access is restricted or the maximum loading of a supporting floor is limited, specialist robotic demolition machines offer much higher power-to-weight ratios than manned excavators. The Brokk 50 can pass through ordinary doorways and climb stairs.

people on the day, so it's a bit like a military operation," says Coleman. "You have to survey and contact each of the properties for any issues such as security and pets. We have to create a safe, sterile environment, which is generally [equivalent to] three times the height of the structure. So, say, if you have a building that is 50-70 metres [164-230 foot] high, you are talking about an exclusion zone in the region of 150-200 metres [492-656 feet].

"Generally, we try to negotiate our way through it without money changing hands. So if you're close to the structure, we'll put you up for the weekend at a hotel. If you're not too close we might look at other proposals, such as locking you into the building and putting a policeman outside. It's all about finding [the safest] process. If you're standing within a few metres of the building you're going to get squashed, but if you're 50 metres [164 feet] away you've got no problem."

A week or two before the day of the demolition, the detonating cord is fed into the holes and grouted firmly in place. This improves the detonation efficiency as the expanding gas from the explosives has nowhere to go and the force is concentrated into the concrete wall.

But it also prevents the explosives from being stolen by opportunist thieves or terrorists. There is no risk of accidental explosion without the detonators, but to be safe the ground floor of the demolition site is still guarded around the clock by specialist security teams.

Demolition day itself is nearly always on a Sunday to minimise the disruption to local traffic and businesses. Around 5am, workers begin surrounding the perimeter of the demolition exclusion zone with security fencing. "Around the fence zone we have sentries, and they all have to have a line of sight between each other so they can maintain visual security of the zone in the event of the radios not working," Coleman explains. "Each sentry will have a police officer with them, so if there is a breach the police will deal with it."

The spider's web of detonation cord laced through the building is brought together into bunches at strategic points, and at about 7am, the explosives engineer begins attaching the detonators to each bunch. Even at this point, key connections are left open in order to ensure absolute safety: "They wait there ready until the team can say, guaranteed, everyone is out. Then we'll start a ten-minute countdown, with a series of final connections carried out in the last few minutes. There's a series of horns that sound to keep everybody alert. There's an electric atmosphere in the air and a deathly silence falls.

"When we're doing the countdown, we'll count from 20 down to ten, and that will be audible over the radios, then you'll hear a shot go, which we use to frighten any birds out of the building. And then everyone will think 'What's happening?' But we've actually started the real ten-second countdown; the purpose of the radio silence is that in those crucial seconds, if someone needs to [stop the blast], all they need to do is say, 'Abort!'."

Incredibly, it takes between just three and five seconds for a 45,000-ton tower block to crumble down into a pile of rubble. Once the dust has settled, the explosives engineer inspects the debris to be certain that all the explosives detonated. Next excavators and street-sweeping machines and workers with brushes and brooms move in to clean up the surrounding area, and the neighbouring

How to implode a tower block

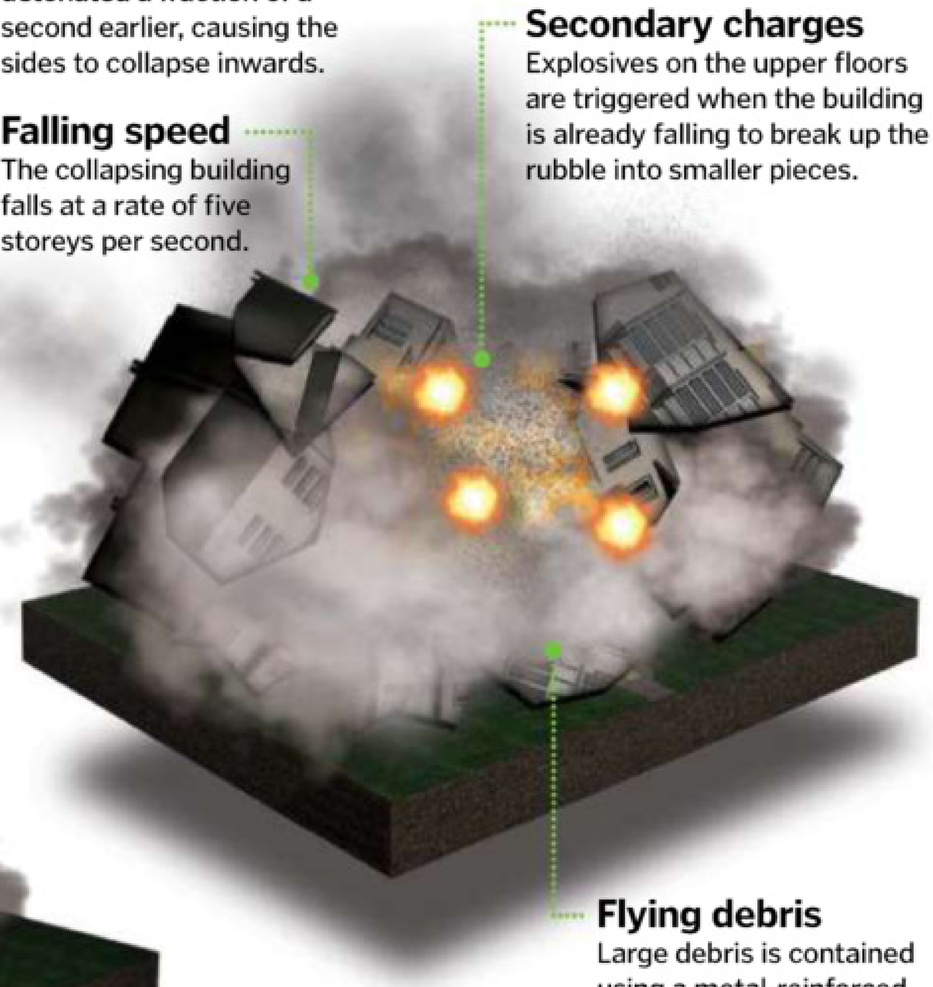
A step-by-step guide to blowing up several thousand tons of concrete and steel with maximum safety and efficiency

residents are allowed back into their homes. "Then we lift the fencing and go off to the pub for a couple of pints," says Coleman. "After that we come back for typically about 12 weeks to munch up all the material and remove it from the site. Once it's all been taken away and we have exposed the slabs of the foundation, they are then broken out, processed and removed, and the void is backfilled and ready for the house builders to take over the site."

A forensic operation

When a building catches fire or partially collapses, it can be so badly weakened that demolishing it is the only way to make it safe. If there are fatalities, the bodies must be carefully extricated. But if arson or negligence is suspected, demolition contractors must try to preserve any evidence for accident investigators. The building has to be peeled away one layer at a time without disturbing the layers below. Sometimes a building actually has to be strengthened before it is torn down to ensure it doesn't collapse in an uncontrolled way.

An exclusion zone with sentries is set up around the demolition site to ensure no one enters



Security cordon
Emergency services and security guards maintain a perimeter to keep the exclusion zone safe.

Staged detonation
The middle of the building is detonated a fraction of a second earlier, causing the sides to collapse inwards.

Falling speed
The collapsing building falls at a rate of five storeys per second.

Clearing up
Wrecking machines and bulldozers break up any pieces still standing and then remove the rubble and foundations.

Secondary charges
Explosives on the upper floors are triggered when the building is already falling to break up the rubble into smaller pieces.

Flying debris
Large debris is contained using a metal-reinforced netting. Dust can be minimised by using large water hoses.

Steel girders
Buildings with heavy steel beams require much more powerful explosives, such as RDX.

© Thinkstock; Alamy; Jorge Royan/www.royan.com.ar; Coleman & Company; Peters & Zabransky

How do buildings rotate?

Explore the panoramic world of structures that like to get in a spin as we uncover the remarkable engineering that powers them

A new breed of architects has decided to make great views and sunbathed living rooms a permanent fixture by creating rotating houses. One of the first spinning homes was the Villa Girasole in Marcellise, Italy. This L-shaped residence sits on a circular base 44 metres (144 feet) in diameter, with three circular rails supporting it. Underneath these are 15 rollerskate-type wheels that run on grooves, all pushed along by two diesel motors attached to a central tower that pulls the building on a 360-degree rotation every nine hours and 20 minutes.

This design has formed the basis of many other rotating homes, such as the Everingham Rotating House in Australia, which was built in 2006 and works on much the same principle. It uses a 200-ton central bearing, 32 outrigger wheels to provide support, while movement is powered by two 500-watt electric motors. The Everingham house can complete a full circle in just half an hour, as well as using computer settings to place one of the wedge-shaped rooms facing toward the Sun.

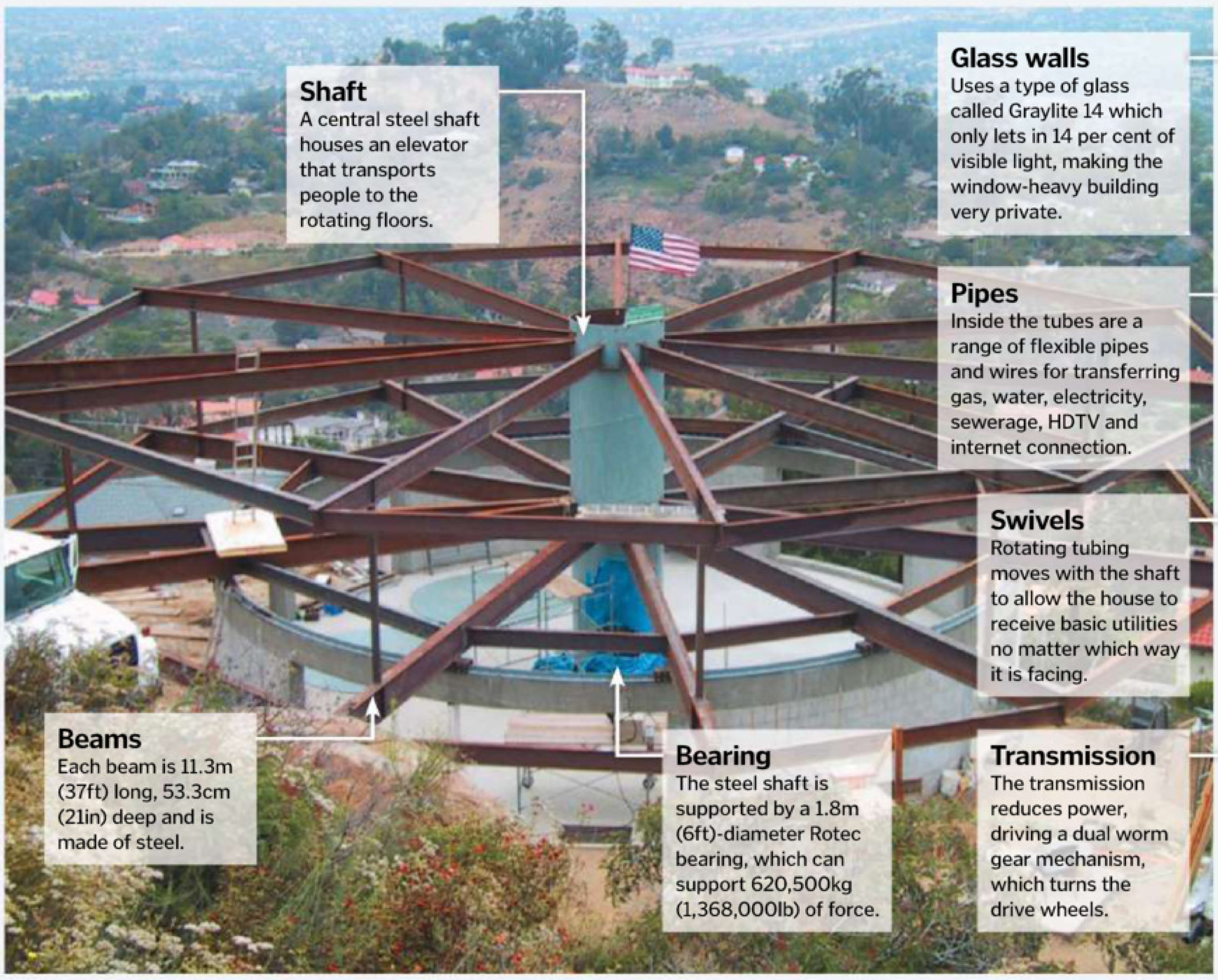
However, if you're looking for a truly eco-friendly rotating building, you can't ignore the Heliotrop in Freiburg, Germany. Powered by a 120-watt electric motor, it only consumes 20 kilowatt-hours per year due to the structure following the Sun to make maximum use of the dual-axis solar panels on its roof. The central column is made of Kerto Q boards from Finland, strengthened by epoxy resin-filled steel ties.

As with all cool structures, there always has to be someone who goes bigger and better and in this particular instance, that person is David Fisher of Dynamic Architecture.

Fisher has drawn out plans for an immense 80-storey building, of which each floor rotates independently. Its revolutionary design also has each floor built in a factory before being attached in complete form to the central tower on site. With developments like these, buildings that continually adapt to their environment could well be the future of architecture.

House on the move

What tech does a building need to do a full 360? Here we focus on the Rotating Home near San Diego, California



Shaft
A central steel shaft houses an elevator that transports people to the rotating floors.

Glass walls
Uses a type of glass called Graylite 14 which only lets in 14 per cent of visible light, making the window-heavy building very private.

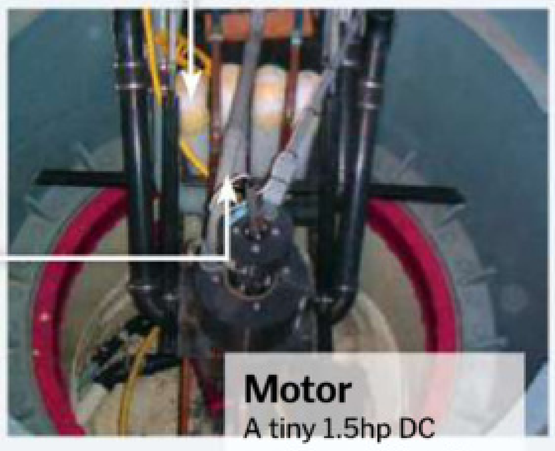
Pipes
Inside the tubes are a range of flexible pipes and wires for transferring gas, water, electricity, sewerage, HDTV and internet connection.

Swivels
Rotating tubing moves with the shaft to allow the house to receive basic utilities no matter which way it is facing.

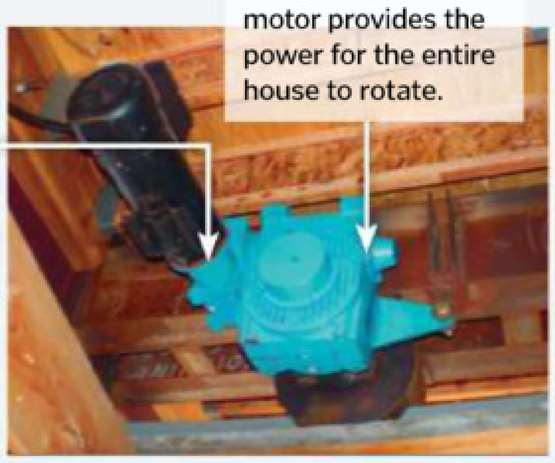
Beams
Each beam is 11.3m (37ft) long, 53.3cm (21in) deep and is made of steel.

Bearing
The steel shaft is supported by a 1.8m (6ft)-diameter Rotec bearing, which can support 620,500kg (1,368,000lb) of force.

Transmission
The transmission reduces power, driving a dual worm gear mechanism, which turns the drive wheels.



Motor
A tiny 1.5hp DC motor provides the power for the entire house to rotate.

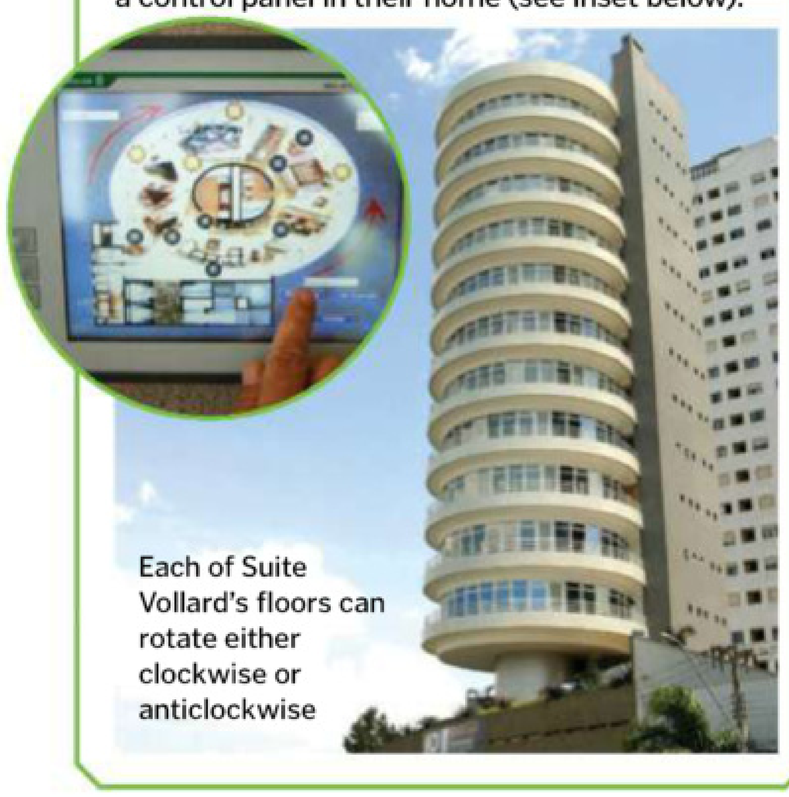


Suites apart

The Suite Vollard became the world's first entirely rotating building, with work on architect Bruno de Franco's building finishing in 2001.

Built in the Ecoville District of Curitiba in Brazil, the 15-storey building has 11 floors of residential apartments that enjoy a single revolution every hour. As with the plans for the Dynamic Skyscraper, all the apartments are built around a static central column made of concrete.

Amazingly a single rotation of the building needs only the same energy as a standard hairdryer. Each apartment is on a separate floor, which means that inhabitants are able to control the speed of their own rotation independently via a control panel in their home (see inset below).



Each of Suite Vollard's floors can rotate either clockwise or anticlockwise

Pioneering spinner

One of the most famous early examples of a building in rotation is the BT Tower in London. This 190-metre (623-foot)-tall TV tower is topped by a restaurant that rotated from its opening in 1966 until it closed in 1980 over security fears.

At the time, the tower was an engineering marvel, completing a full rotation every 22 and a half minutes, offering diners a panoramic view of the London skyline. The construction only required a two-horsepower electric motor to power the 0.27-kilometre (0.17-mile)-per-hour rotation. Allowing the top of the tower to move was a series of nylon bearings and rollers.

Despite being stationary today, the BT Tower remains one of London's most iconic landmarks and it has provided inspiration for many of the fully rotating buildings emerging today.

The Heliotrop in Freiburg, Germany, actually uses rotation to save energy, via solar panels on the roof

Left: The Space Needle in Seattle, USA, has an observation deck and a rotating restaurant at the top

© Alamy; Corbis; Rolf Disch Solar Architecture, Freiburg, Germany; RotatingHome.com

The Three Gorges Dam is estimated to increase national energy output by ten per cent at full capacity

Spillway
Controls the release of water from the reservoir and stops the water from overflowing and destroying the dam.

Power generators
Water from the reservoir drops through the dam via two power houses (inside), turning turbines that generate more electricity than all of the UK's nuclear power plants combined.

Direction of river flow

Dam engineering

How these structures are built to withstand immense natural forces

Building any dam presents a unique engineering challenge, since no landscape or water system is exactly the same. One of the best sites to build a dam is in a narrow river valley with steep rocky sides strong enough to support the structure. The first step is to divert the water around the area you want to build, and for large dams in rocky environments, explosives are used to blast a new channel through the terrain. A temporary barrier is needed to keep water out of the area normally submerged. Traditionally, a wet concrete mixture is poured into moulds, hardening to form the shape of the intended dam. Gravity dams, meanwhile, like the Three Gorges Dam in China have walls with steep slopes, and rely solely on their immense weight to hold the water back. Arch dams, like the Hoover Dam in the USA, use their curved shape to balance out the pressure. Buttress dams get their strength from concrete pillars lined along the face of the structure, and embankment dams slope gradually and are made from compacted earth. The world's largest dams weigh millions of tons, making strong foundations that reach deep below the original ground level essential.

History of dams

The first dams were simple gravity dams made of masonry. The Ancient Egyptians were the first to realise dams could alleviate floods. In 2650 BCE, work began on a large embankment dam called Sadd el-Kafara. At 110 metres (360 feet) long and 14 metres (46 feet) tall, it would have been the largest in the world, but a flood destroyed it before it was finished. Marduk Dam in Mesopotamia, from circa 2000 BCE, was the first embankment dam, built to prevent flooding and to irrigate crops.

The Romans embraced dam building, using them to transport, store and distribute water in new ways – and at least two Roman dams are still used today. Modern dam construction took off in the mid-19th century as knowledge of structural theory and materials science came to light.

THE STATS
THREE GORGES

WEIGHT 65mn tons HEIGHT **185m** STARTED OPERATING 2003

BREADTH **2km** BUILD TIME 17yrs OUTPUT **22,500MW**

DID YOU KNOW? *Building the Three Gorges Dam raised so much water that the Earth's rotation slowed slightly*

Reservoir
1,050km² (405mi²) of water covers once inhabited land. It called for the relocation of 1.3 million people.

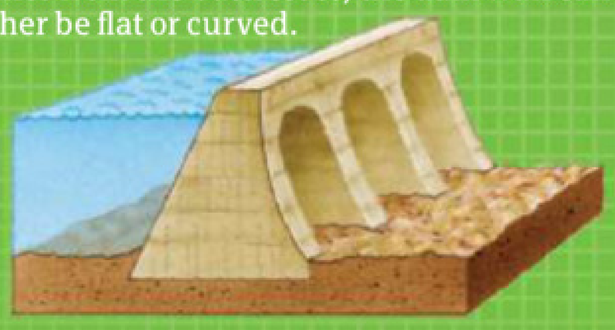
Ship lock
A two-way, five-stage lock enables large vessels weighing up to 10,000 tons to pass.

Ship lift
A 113m (370ft) 'elevator' for smaller ships that weigh around 3,000 tons is due to be completed in 2015.

Three major types of dam

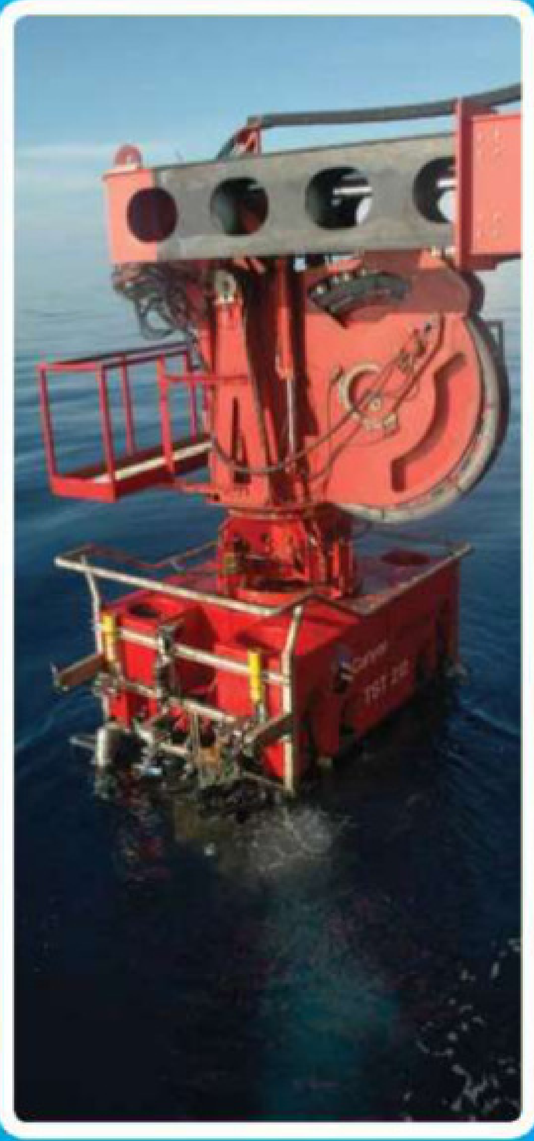
Embankment dam
Made from a bank of earth, these dams rely on their intense weight and sloped shape to hold the water back. There may be an impervious layer of concrete, plastic or other material on the upstream face if the particle sizes in the earth are big enough for water to seep through. Earth-filled dams can be made completely from one type of material, but may need a layer that collects and drains seep-water to ensure the structure stays intact.

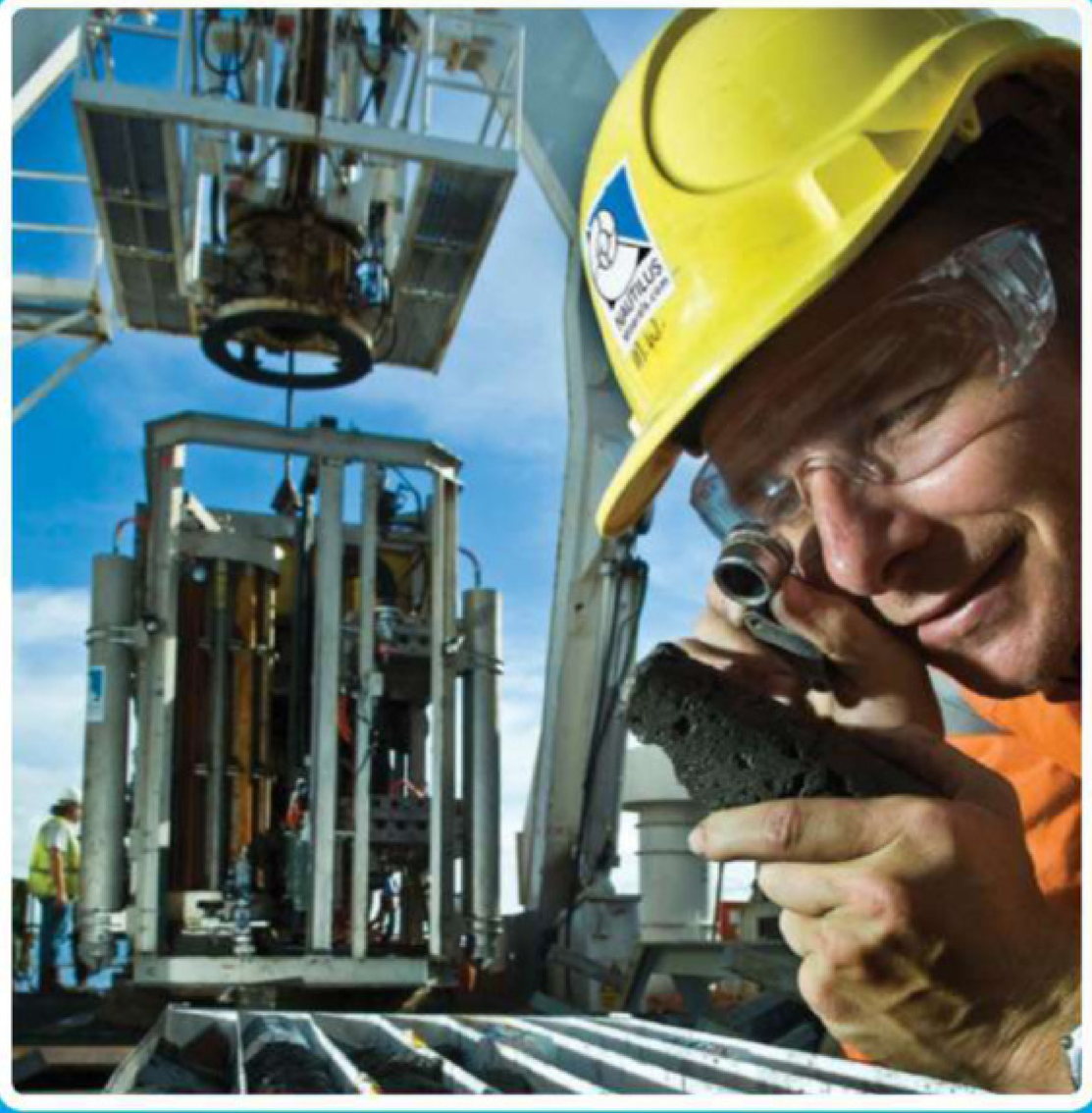
Buttress dam
Buttress dams are used when the surrounding rock is not strong enough to provide a solid foundation. A series of solid concrete buttresses lined along the downstream face of the dam provide the strength needed to hold it in place. Buttresses add weight to the structure, pushing towards the ground and anchoring the dam even further. Since most of the support comes from the buttresses, the dam wall can either be flat or curved.



Arch dam
Best for narrow rocky ravines with steep walls strong enough to support the structure, these are solid concrete structures that curve upstream, forming an arch. The pressure from the water is distributed evenly for structural integrity, similar to an arch bridge. The weight of the dam pushes it into the ground, helping to reinforce it. Examples that are double-curved horizontally and vertically are referred to as dome dams.

© SPL; Thinkstock





DEEP-SEA MINING

Massive remote-controlled machines are poised to brave extreme elements to launch an underwater gold rush

Man landed on the Moon in 1969, but it would be nearly another decade before we discovered a remarkably alien world right here on Earth. In 1977, a group of geologists sent an unmanned submersible vehicle thousands of metres down to the seafloor off the coast of the Galápagos Islands. They were searching for proof of plate tectonics, the theory that the Earth's crust not only shifted, but was perpetually consumed and reborn at volcanically active seams.

What they found at the bottom of the ocean would revolutionise both geology and biology. In the middle of a vast, featureless desert they discovered otherworldly rock towers, some measuring 30 metres (98 feet) in height, each of them teeming with previously unseen life forms, including snails the size of a fist, tubeworms measuring three metres (9.8 feet) long, paper-white crabs, purple octopi and swarms of shrimp. The fuel for this explosion of life was the boiling-hot fluid spewing from the top of each tower. Rich with minerals, it supported thriving colonies of bacteria, which in turn provided nutrients to increasingly more complex deep-sea life.

Geologists labelled these deepwater seams 'hydrothermal vents', and thousands more would be located atop every undersea fault line from the Pacific's 'Ring of Fire' to the Mid-Atlantic Ridge. When scientists analysed samples of rock taken from hydrothermal vents, they found unique chemical and mineral properties. The large rock towers were mostly pyrite – an iron sulphide – and other sulphide-dominant rocks. Trapped in these sulphides were high quantities of metallic elements like copper, zinc, and even gold and silver.

Why exactly are hydrothermal vents so packed with valuable minerals? It has to do with heat and pressure. The pressure on the deep ocean floor is 160 times greater than at sea level. This forces seawater downward through cracks and seams in the floor. In volcanically active areas, that water comes into contact with shallow reservoirs of magma, heating it to hundreds of degrees and triggering chemical reactions that strip the seawater of oxygen, magnesium and other elements.

As the super-heated seawater percolates toward the surface, its acidity leeches minerals like copper, zinc and iron from surrounding rock. When the hot, mineral-laced water flows out into the deep ocean, it meets surrounding seawater that's oxygen-rich and nearly freezing cold. The clash of these two extremes triggers another series of chemical reactions in which valuable minerals precipitate out of solution and solidify to form metal-rich towers.

The mining industry has known about this deep-sea treasure for a few decades, but the cost and technical difficulty of digging a mile deep into the seafloor has been daunting. Previous efforts to harvest manganese nodules – potato-sized nickel balls, copper and rare minerals – from the deep ocean floor proved financially disastrous.

5 TOP FACTS
MARINE MINING

Gold rush
1 If deep-sea mining companies could retrieve all of the gold believed to exist in seabed deposits, it's estimated that it would be worth in the region of £94 trillion ($150 trillion).

A Roman industry
2 Ancient Rome mined volcanic deposits on Cyprus for copper ore. Seafloor massive sulphide (SMS) deposits are deep-water examples of this same phenomenon.

Saltwater diamonds
3 The diamond giant De Beers mines the shallow ocean floors (90-140m/295-460ft) off South Africa, where the Orange River deposits diamond-rich silt into the sea.

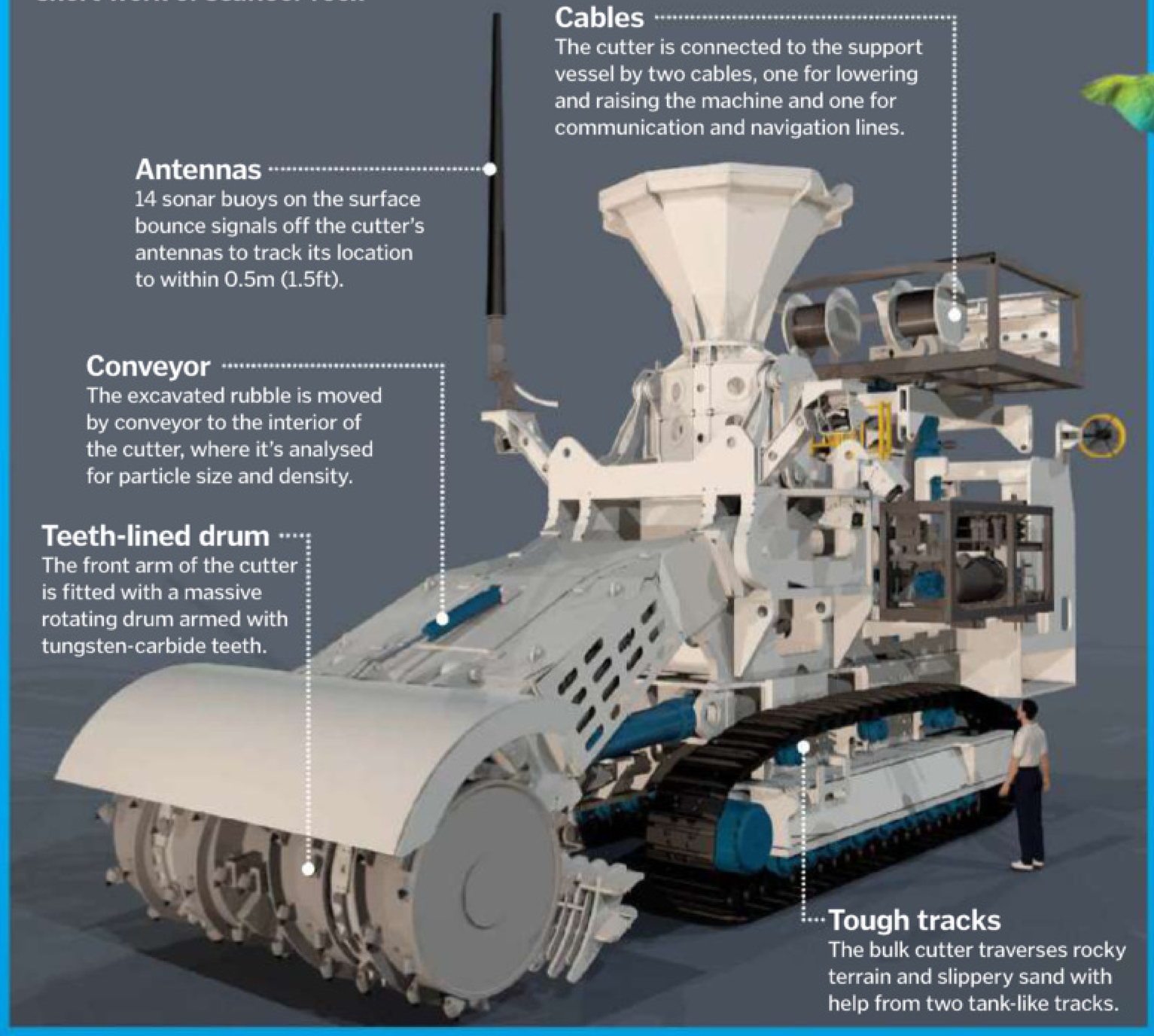
Vent colonies
4 Scientists debate the impact of mining on deep-sea life around hydrothermal vents. As long as new vents are available, some argue that these lifeforms will still thrive.

Mining for good
5 Deep-sea mining is a potential source of revenue for developing nations. Even operations in international waters must share profits with developing countries.

DID YOU KNOW? *Geologists estimate that seabed mineral deposits have enough ore to give everyone on Earth 4kg (9lb) of gold*

The bulk cutter up close

Part tank, part voracious grinder, the bulk cutter makes short work of seafloor rock



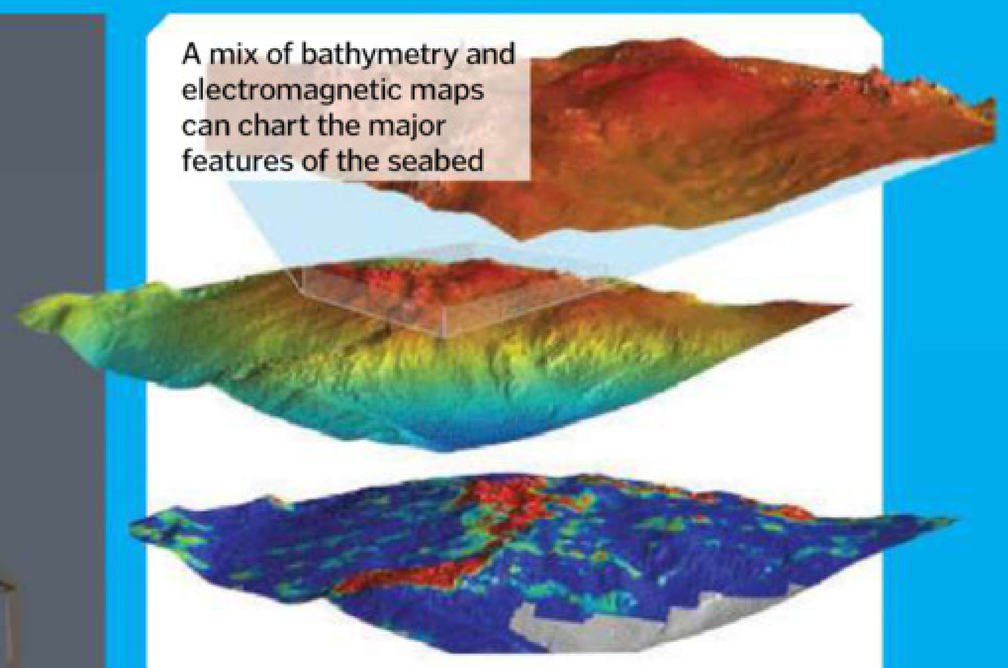
Cables
The cutter is connected to the support vessel by two cables, one for lowering and raising the machine and one for communication and navigation lines.

Antennas
14 sonar buoys on the surface bounce signals off the cutter's antennas to track its location to within 0.5m (1.5ft).

Conveyor
The excavated rubble is moved by conveyor to the interior of the cutter, where it's analysed for particle size and density.

Teeth-lined drum
The front arm of the cutter is fitted with a massive rotating drum armed with tungsten-carbide teeth.

Tough tracks
The bulk cutter traverses rocky terrain and slippery sand with help from two tank-like tracks.



A mix of bathymetry and electromagnetic maps can chart the major features of the seabed

Mapping minerals

The map of global seafloor mineral deposits looks exactly like an outline of the planet's tectonic plates. When two plates converge or diverge under the sea, mineral-rich fluids escape through the seams in the Earth's crust. On land, these geothermal vents might look like gurgling mud pots or geysers. On the seafloor, the minerals inside the blazing hot fluids cool and precipitate into rocky deposits called seafloor massive sulphides rich with zinc, copper, silver, gold and other rare elements. These deep-sea mineral fields ring the coastal waters of the Pacific and line the Mid-Atlantic Ridge. The hottest spot for potential deep-sea mining exploration is the western South Pacific near the coasts of Papua New Guinea and Australia. The majority of the seafloor is considered beyond the jurisdiction of individual nations, and is therefore controlled by the International Seabed Authority, which has so far issued 17 exploratory permits to private companies and governments including China, Russia, India and France.

But a hot market for minerals and heavy investment in seafloor mining technology has set the stage for a deepwater gold rush. Nautilus Minerals, a seafloor mining company based in Toronto, Canada, wants to be the first in the water. With help from UK heavy machinery manufacturer Soil Machine Dynamics (SMD), Nautilus has built massive robotic cutters and excavators to pulverise mineral-rich seafloor deposits, pump the debris to the surface and sift out the treasure. The target site is an outcropping of vents off the coast of Papua New Guinea believed to contain enough copper, gold, silver and zinc to fetch £1.8 billion ($2.9 billion) on the open market.

"Trapped in these sulphides were high quantities of metallic elements like copper, zinc, and even gold and silver"

Nautilus's highly specialised mining machines are 300-ton beasts that combine the brute force of terrestrial continuous mining equipment with high-end technology like HD video cameras and 3D sonar that allows them to be operated remotely at depths of 1.6 kilometres (one mile). The company will employ three vehicles – known as seafloor production tools – each with its own critical mission: the auxiliary cutter, the bulk cutter and the collecting machine.

The business end of the auxiliary cutter is a cluster of four rotating drums fitted with a total of 200 tungsten-carbide teeth. Mounted on a long boom, the spinning teeth are tasked with chewing up mineral deposits on steep or uneven gradients, including those towering hydrothermal vents.

The bulk cutter is 14.2 metres (46.6 feet) long by 4.2 metres (13.8 feet) wide and leads with a rotating cylinder studded with 7.6-centimetre (three-inch) teeth. The bulk cutter shreds rock on seafloor contours and flat benches carved out by the auxiliary cutter. Both the bulk and auxiliary cutters grind the rock to diameters smaller than five centimetres (two inches).

The collecting machine is like a monstrous wet/dry vacuum, sucking up a slurry of pulverised rock, silt and seawater with a long adjustable arm capped with a spinning, sifting nose. The collecting machine draws the material into its body, where sensors can measure the slurry's density, flow rate, temperature and pressure.

The next stop is the 120-ton subsea pump built by GE, designed for mining jobs that need the high-flow transport of rocky slurry and mud. The massive ten-chamber pump is suspended by cables from the support vessel floating a mile up. The seafloor vehicles is also connected to the vessel by cables that carry

communication, power and navigation lines.

The pump forces the rock-studded material up a 30-centimetre (12-inch) rigid rubber pipe reinforced with steel and Kevlar. On the support vessel, the slurry is fed into a dewatering plant, where liquids are filtered and spun out to leave dry, rocky debris. The plan is to have barges ferry the material 50 kilometres (31 miles) to a storage facility in the Papua New Guinea port of Rabaul, after which the minerals can be extracted and concentrated into marketable ore.

Seafloor mining holds tremendous promise, but still has to overcome a number of difficult challenges. The first is obtaining the rights to mine the deep ocean. In the case of Nautilus, the company signed a 20-year mining lease with Papua New Guinea, one of few nations that actually owns mineable seafloor deposits. Most hydrothermal vents exist in international waters, where they are regulated by the UN-sanctioned International Seabed Authority, which is slower to sell exploration rights.

The second obstacle is increasing pressure from environmental groups and marine biologists, who worry about the impact of mining on the little-understood plants and animals that thrive in the extreme environments of the vents. Seafloor mining will certainly destroy some of those habitats, but will the sealife be able to successfully relocate to undisturbed vents? This and many other questions remain to be answered.

In the meantime, Nautilus and a handful of other international players are preparing to take their mining machines to the high seas, in order to hunt the depths for a treasure bounty the likes of which has never been seen.

Mining conditions in the depths

The conditions of life thousands of metres below the ocean surface are otherworldly. Pressure is so intense that the fluids seeping from deep-sea vents are neither liquid nor gas, but something in between – not to mention those fluids are highly corrosive, acidic and searing at temperatures over 315 degrees Celsius (600 degrees Fahrenheit). At a short distance from the hydrothermal vents, the temperature of surrounding deep-sea waters is close to freezing. These brutal conditions pose tremendous technical challenges to mining operations, including the construction of robotic machinery that can operate in such temperature and pressure extremes, not unlike landing a mining rig on a passing asteroid.

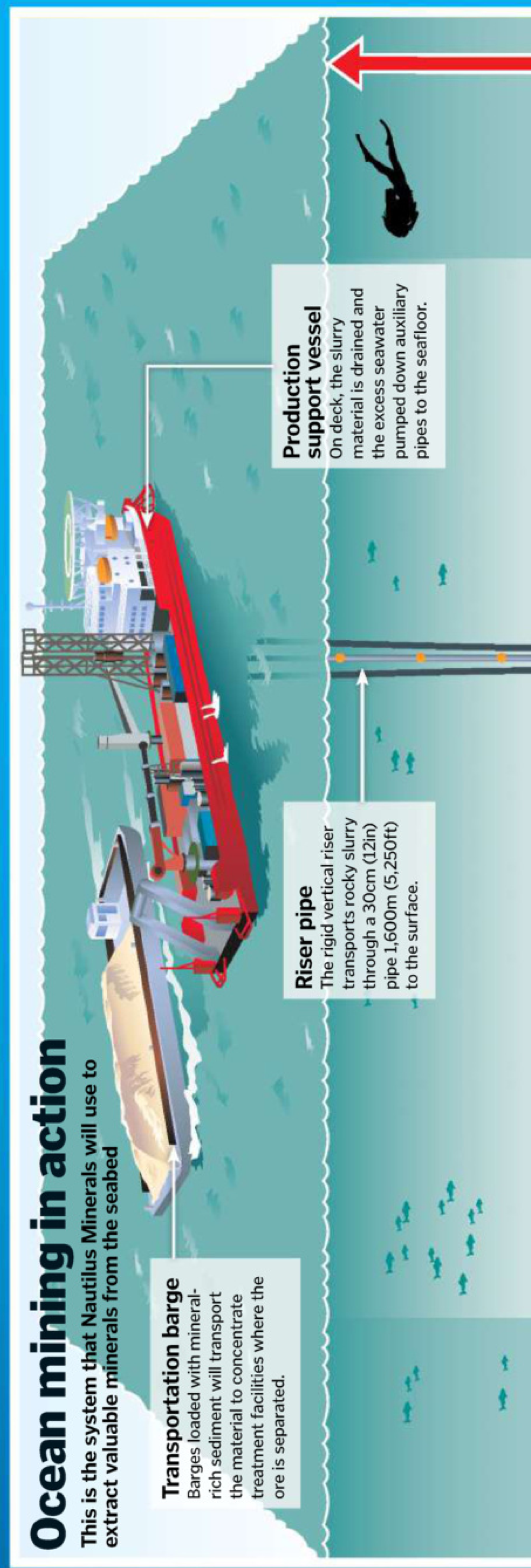
Mining out the facts

We speak to John Elias from Nautilus Minerals about the major challenges that deep-sea mining presents

What are you searching for under the ocean that we can't get on land?
Nautilus Minerals is the first company to explore the ocean floor for polymetallic seafloor massive sulphide (SMS), which contains appreciable amounts of copper, gold, silver and zinc. They are formed predominately along tectonic fault lines where hot magma containing high concentrations of dissolved minerals seeps out of the earth and mixes with cold seawater, which causes the minerals to precipitate and form these deposits on the ocean floor. Compared to land-based porphyry copper mines, SMS deposits contain copper in concentrations that are ten times higher. For example, Solwara 1, Nautilus's maiden project, has an average copper concentration of about seven per cent copper, while land-based copper mines average about 0.6 per cent.

How do you find a site to dig underwater?
Nautilus has employed a number of techniques for identifying prospective sites. One is mapping bathymetry by sonar, to look for areas of recent or current volcanic activity. Another is sampling and measuring the properties of the water column, looking for large-scale ash plumes that result from volcanic activity that is typically associated with seafloor massive sulphide mineralisation. We also traverse over the seafloor in areas where we found ash and metal anomalies in the water column to locate seabed expressions of the mineralisation. This is using a remotely operated vehicle (ROV) that takes small samples of rock. Lastly, we use geophysics and drilling activity to estimate the actual resource of metal contained at the most promising SMS discoveries. There is practically no impact on the environment from these exploration activities, apart from the presence of a ship. Even the drilling is a much lower impact than land, because we do not need to clear access tracks to get the drill rig in.

How does sea-mining differ from on land?
Nautilus developed a seafloor production system composed of seafloor production tools (SPTs), the riser and lifting system (RALS) and the production support vessel. There are a number of aspects that differentiate Nautilus's mining methodology from its land-based counterparts. Unlike land-based mines, the system Nautilus developed features an infrastructure (the SPTs, the RALS and the vessel) that can be relocated from one mining site to another. No roads have to be built to reach the deposit and no communities need to be relocated. The high grades combined with a relatively small amount of overburden ensure seafloor SMS deposits like Solwara 1 will have a smaller physical footprint than its land-based counterparts. Mineral deposits on land are increasingly of lower grade, which means more waste is being created per ton of metal produced.



Ocean mining in action
This is the system that Nautilus Minerals will use to extract valuable minerals from the seabed

27bn

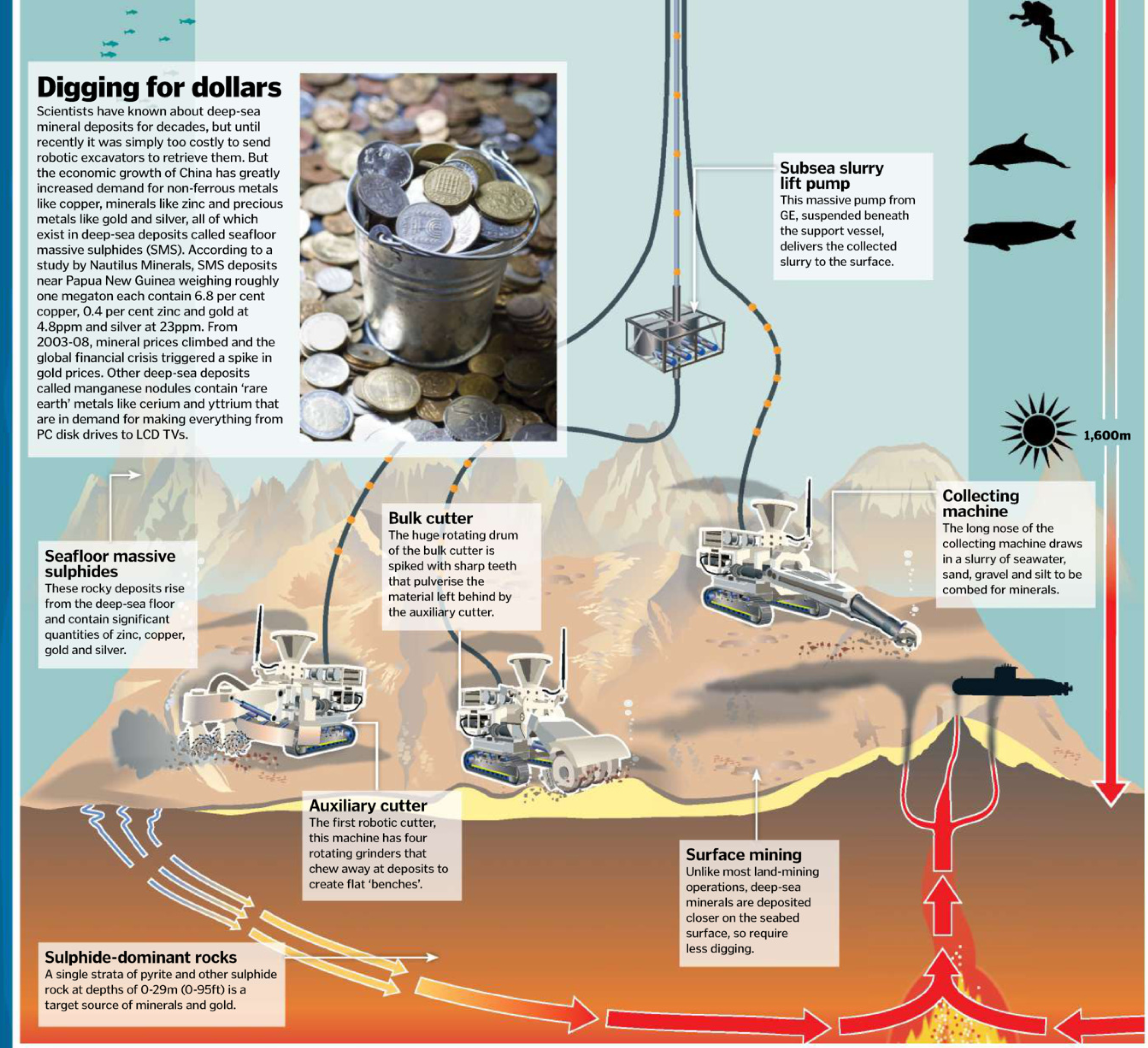
FIELDS OF MANGANESE NODULES

Geologists debate how these rock clusters form, but estimate that the eastern Pacific seafloor holds more than 27 billion tons of the nodules rich in manganese (29 per cent), as well as nickel (1.3 per cent), copper (1.1 per cent) and other metals.

DID YOU KNOW? *At 1,600m (5,250ft) below the ocean surface, the pressure is 160 times greater than at sea level*

Digging for dollars

Scientists have known about deep-sea mineral deposits for decades, but until recently it was simply too costly to send robotic excavators to retrieve them. But the economic growth of China has greatly increased demand for non-ferrous metals like copper, minerals like zinc and precious metals like gold and silver, all of which exist in deep-sea deposits called seafloor massive sulphides (SMS). According to a study by Nautilus Minerals, SMS deposits near Papua New Guinea weighing roughly one megaton each contain 6.8 per cent copper, 0.4 per cent zinc and gold at 4.8ppm and silver at 23ppm. From 2003-08, mineral prices climbed and the global financial crisis triggered a spike in gold prices. Other deep-sea deposits called manganese nodules contain 'rare earth' metals like cerium and yttrium that are in demand for making everything from PC disk drives to LCD TVs.



Subsea slurry lift pump
This massive pump from GE, suspended beneath the support vessel, delivers the collected slurry to the surface.

Collecting machine
The long nose of the collecting machine draws in a slurry of seawater, sand, gravel and silt to be combed for minerals.

Bulk cutter
The huge rotating drum of the bulk cutter is spiked with sharp teeth that pulverise the material left behind by the auxiliary cutter.

Seafloor massive sulphides
These rocky deposits rise from the deep-sea floor and contain significant quantities of zinc, copper, gold and silver.

Auxiliary cutter
The first robotic cutter, this machine has four rotating grinders that chew away at deposits to create flat 'benches'.

Surface mining
Unlike most land-mining operations, deep-sea minerals are deposited closer on the seabed surface, so require less digging.

Sulphide-dominant rocks
A single strata of pyrite and other sulphide rock at depths of 0-29m (0-95ft) is a target source of minerals and gold.

© Ian Moores Graphics; Nautilus Minerals; Thinkstock

Harnessing tidal power

How do these marine power plants turn the sea's motion into electricity?

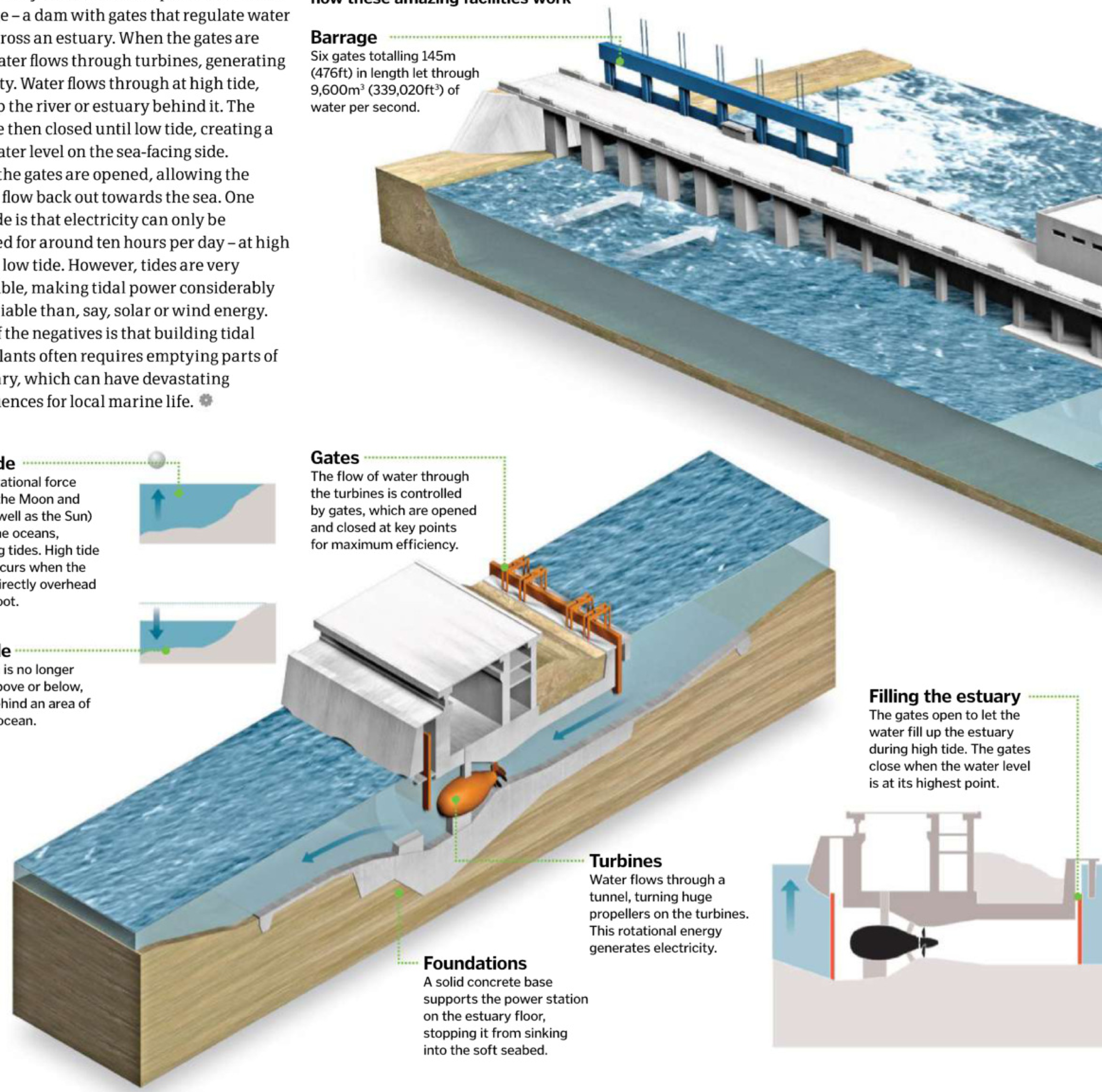
Tidal power plants use the rise and fall of tides to produce electricity. One way to harness tidal power is to build a barrage – a dam with gates that regulate water flow – across an estuary. When the gates are open, water flows through turbines, generating electricity. Water flows through at high tide, filling up the river or estuary behind it. The gates are then closed until low tide, creating a lower water level on the sea-facing side.

Next, the gates are opened, allowing the water to flow back out towards the sea. One downside is that electricity can only be generated for around ten hours per day – at high tide and low tide. However, tides are very predictable, making tidal power considerably more reliable than, say, solar or wind energy.

One of the negatives is that building tidal power plants often requires emptying parts of an estuary, which can have devastating consequences for local marine life.

Turning tides into electricity

Using the Rance tidal power station as a case study, we see how these amazing facilities work



Barrage
Six gates totalling 145m (476ft) in length let through 9,600m³ (339,020ft³) of water per second.

High tide
The gravitational force between the Moon and Earth (as well as the Sun) pulls on the oceans, generating tides. High tide usually occurs when the Moon is directly overhead or underfoot.

Low tide
The Moon is no longer directly above or below, leaving behind an area of low-level ocean.

Gates
The flow of water through the turbines is controlled by gates, which are opened and closed at key points for maximum efficiency.

Filling the estuary
The gates open to let the water fill up the estuary during high tide. The gates close when the water level is at its highest point.

Turbines
Water flows through a tunnel, turning huge propellers on the turbines. This rotational energy generates electricity.

Foundations
A solid concrete base supports the power station on the estuary floor, stopping it from sinking into the soft seabed.

254MW

BIGGEST TIDAL POWER STATION

Sihwa Lake Tidal Power Station, located in South Korea, was finished in 2011 and can pump out 254 megawatts of electricity – enough to power 50,000 homes.

DID YOU KNOW? *Tidal power is the only technology to work from gravitational energy in the Earth/Moon orbital system*

The AK1000 is one of the most powerful single axis tidal turbines on Earth

Location
The power station sits in the La Rance estuary, where water flows into the English Channel.

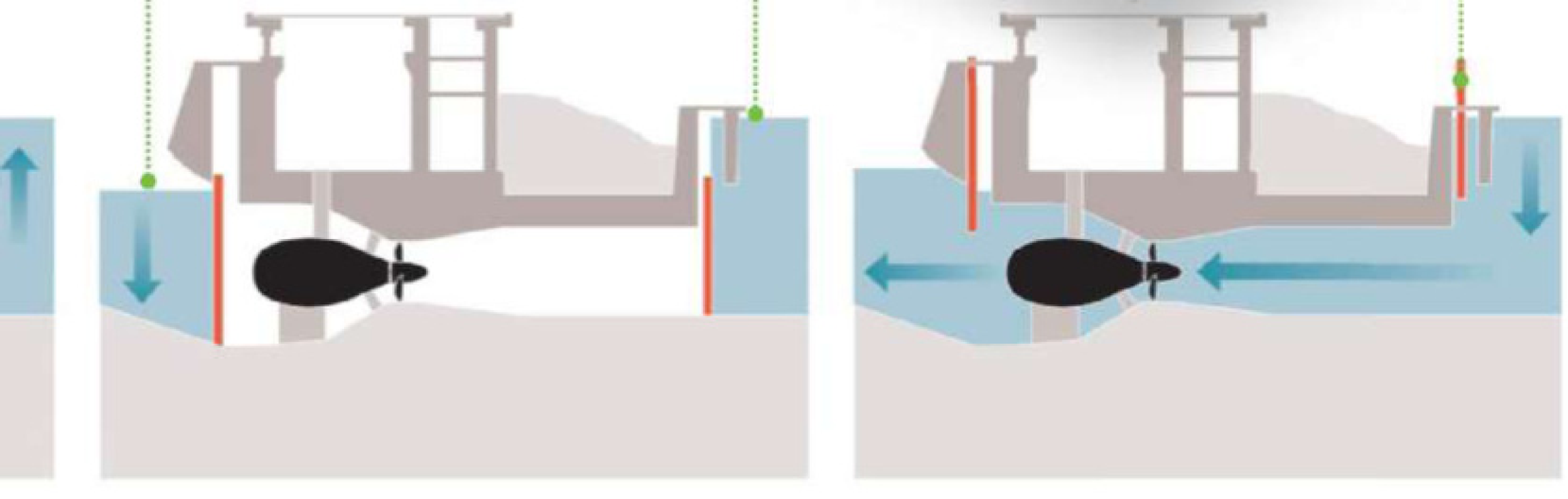
Turbines
Water flows through 24 turbines, transferring kinetic energy from the water into electricity.

Electrical substation
Voltage is stepped up from low to high to make it suitable for the national grid.

High-voltage grid
The electricity is distributed from here, powering towns and cities in northern France.

Changing water levels
Low tide creates a difference in water level between the two sides of the barrage.

Generation
The open gates allow water from the estuary to flow back through the tunnel, turning the turbines to generate electricity.



Rance: the first tidal power station

The Rance Tidal Power Station, situated on the Rance River estuary in France, was built in 1966. The site was chosen for its extreme tide levels – an average of eight metres (26 feet) difference between high and low tide. Two temporary dams were made to allow drainage of the construction site, protecting it from the sea. It is still the second largest in the world today, the biggest being the Sihwa power station in South Korea.

© Solgo Images; Alamy

Inside a pyrometer

The tool that's tough enough to measure superhot objects

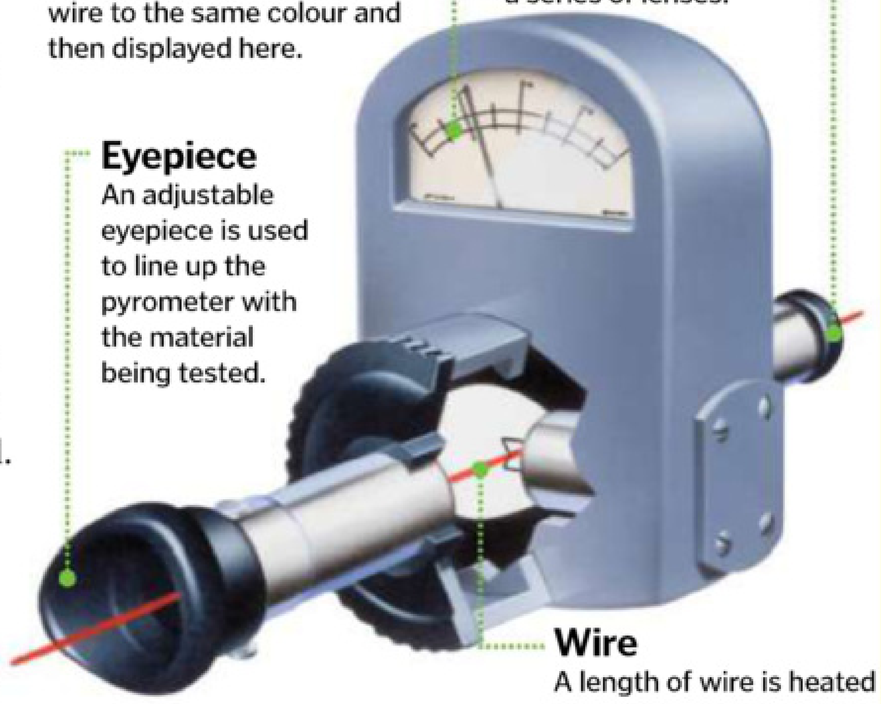
To measure the temperature of objects hot enough to melt more traditional thermometers, a pyrometer is often used. These specialist thermometers use the electromagnetic radiation released by extremely hot objects to determine their temperature from a distance.

As objects heat up they release infrared and visible light, which can be used to determine their temperature. An optical pyrometer contains a metal wire, which can be heated using a variable electrical current; as the wire is heated, it changes colour. By matching the colour of the wire to the colour of the object being tested, an approximate temperature can be deduced.

A more accurate reading is obtained by focusing the electromagnetic radiation on temperature-sensitive electrical components. The components then produce a variable current, depending on the heat level.

Optical pyrometer up close

This simple piece of kit can safely calculate the temperature of scorching-hot objects



Origins in the pottery trade

Founder of the Wedgwood pottery company, Josiah Wedgwood, invented the pyrometer in the 18th century to measure the temperature of his kilns. Clay changes colour depending on the temperature at which it is fired. Wedgwood made a series of pieces of clay, fired at known temperatures, ranging in colour from buff (low temperature) to red (high temperature).

Using these as a guide, he was then able to determine the temperature of the kiln by comparing the colour of the clay to his predetermined reference scale. Wedgwood was elected to the Royal Society in 1783 in recognition of his scientific achievements.

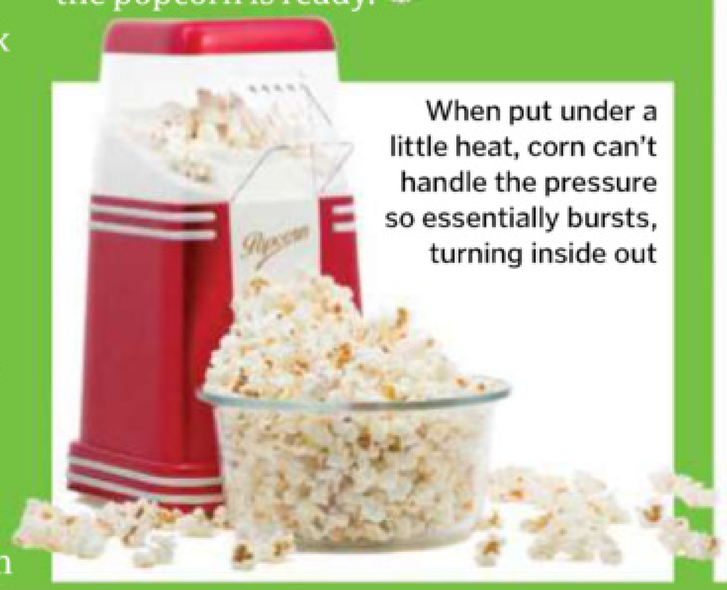
Popcorn machines

Popcorn makers rapidly turn hard corn kernels into fluffy popcorn, but how do they do it?

Dried corn kernels contain about 12-15 per cent water, which turns to vapour when heated. As the steam expands, pressure builds up inside the tough outer shell of the kernel until eventually the corn bursts. The starch granules inside the kernel become gelatinous when heated and expand outwards to form a network of jelly-like bubbles. As they cool, they solidify to leave the puffy, white snack we are all familiar with.

Traditionally, popcorn makers use hot oil to convert the internal moisture of the kernels to steam, but hot air can also be used. Within the main chamber of a popcorn maker there is an electric heating element, which warms the oil or air. The kernels are placed inside the chamber and mixed continually by a fan or rotating blade to prevent them from burning before they reach the temperature required to pop.

The lid of these devices is quite light and often on a hinge, so that as the popped kernels build up inside the chamber the lid lifts, letting you know the popcorn is ready.



When put under a little heat, corn can't handle the pressure so essentially bursts, turning inside out

Popping corn in action

See, step by step, how this movie snack is made

© Thinkstock; Alamy

Swimming pool designs

Take the plunge to see the hidden technology that keeps pools safe and clean

At first glance, a swimming pool might just look like a huge basin filled with water, but hidden beneath the surface is a surprising amount of technology.

The water is constantly circulated through a filtration system, passing out of the main pool through two or more drains at the bottom as well as 'skimmer' drains located around the sides. The main drains collect any debris that sinks to the bottom of the pool, while the skimmer drains take in small amounts of surface water in order to sift out any floating contamination, like hair, bugs and leaves.

The water is drawn through the system by an electric motor, which drives a pump. As the water flows towards the pump a sieve removes any large debris. The water then enters the filtration system, which contains high-grade sand in a vertical column. Gravity pulls the water through the sand and small particulates become trapped in the tiny grains, before the cleaned water passes back out into the pool.

The pump system generates powerful suction, which could create dangerous vortices; the main drains have anti-vortex covers to prevent this. Using multiple drainage points also minimises the risk of people being trapped by suction; if one drain becomes blocked, the pump draws water from the others, decreasing the suction and dislodging the blockage.

Heaters are often included in the pump system to warm the water as it passes through; a thermostat switches the heater on and off to maintain a comfortable temperature.

Focus on chlorine

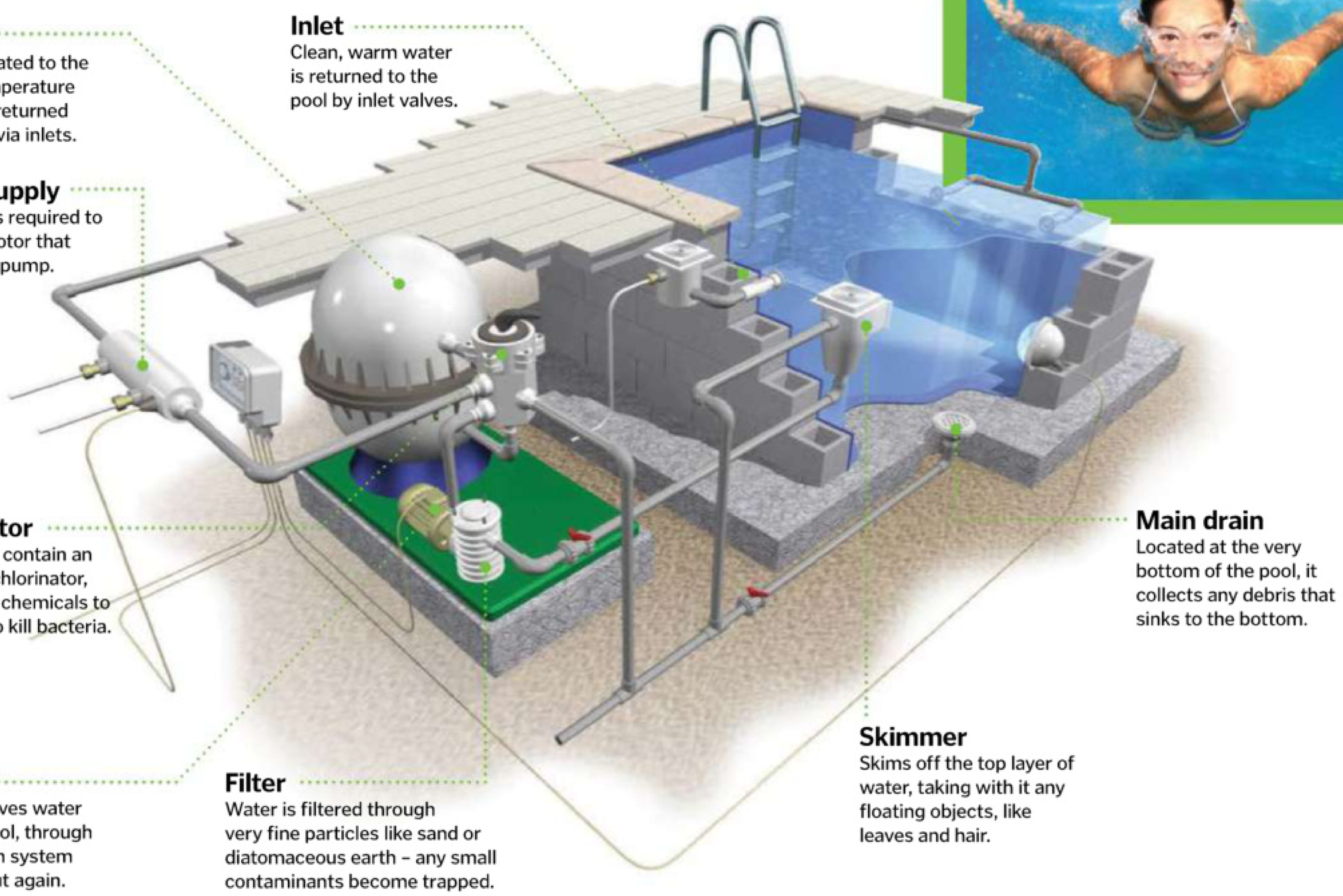
The majority of the technology in a swimming pool is designed to keep it free of debris and to maintain water temperature. But microscopic organisms thrive in warm, still water, so to keep the pool safe, chemical sterilisation is often used.

Chlorine – either in the form of calcium hypochlorite or sodium hypochlorite – is added as a disinfectant. It reacts with water to form hypochlorous acid, which interferes with bacterial cell walls, DNA and enzymes.

Hypochlorous acid breaks down when exposed to UV light though, which is particularly problematic in outdoor swimming pools. Often a stabilising agent is added to keep the chlorine in a usable form for longer. Hypochlorous acid also reacts with ammonia (found in urine) to form compounds called chloramines, which smell bad and can irritate the eyes. A careful balance of chlorine and stabilisers must be maintained to keep the pool safe yet comfortable to swim in.

Beneath the surface...

The underground plumbing of a swimming pool filtration system



Heater
Water is heated to the desired temperature before it is returned to the pool via inlets.

Inlet
Clean, warm water is returned to the pool by inlet valves.

Power supply
Electricity is required to drive the motor that powers the pump.

Chlorinator
Many pools contain an automatic chlorinator, which adds chemicals to the water to kill bacteria.

Main drain
Located at the very bottom of the pool, it collects any debris that sinks to the bottom.

Pump
A pump moves water from the pool, through the filtration system and back out again.

Filter
Water is filtered through very fine particles like sand or diatomaceous earth – any small contaminants become trapped.

Skimmer
Skims off the top layer of water, taking with it any floating objects, like leaves and hair.

© Thinkstock

Ivanpah Solar Power Facility

See how the most advanced solar-powered energy generation site produces electricity

The Ivanpah Solar Power Facility is a brand-new solar thermal power site located in the Mojave Desert in western USA. The facility, which consists of three state-of-the-art thermal power plants lies 64 kilometres (40 miles) south-west of Las Vegas and has a total capacity of 392 megawatts, making it one of the largest of its kind in the world.

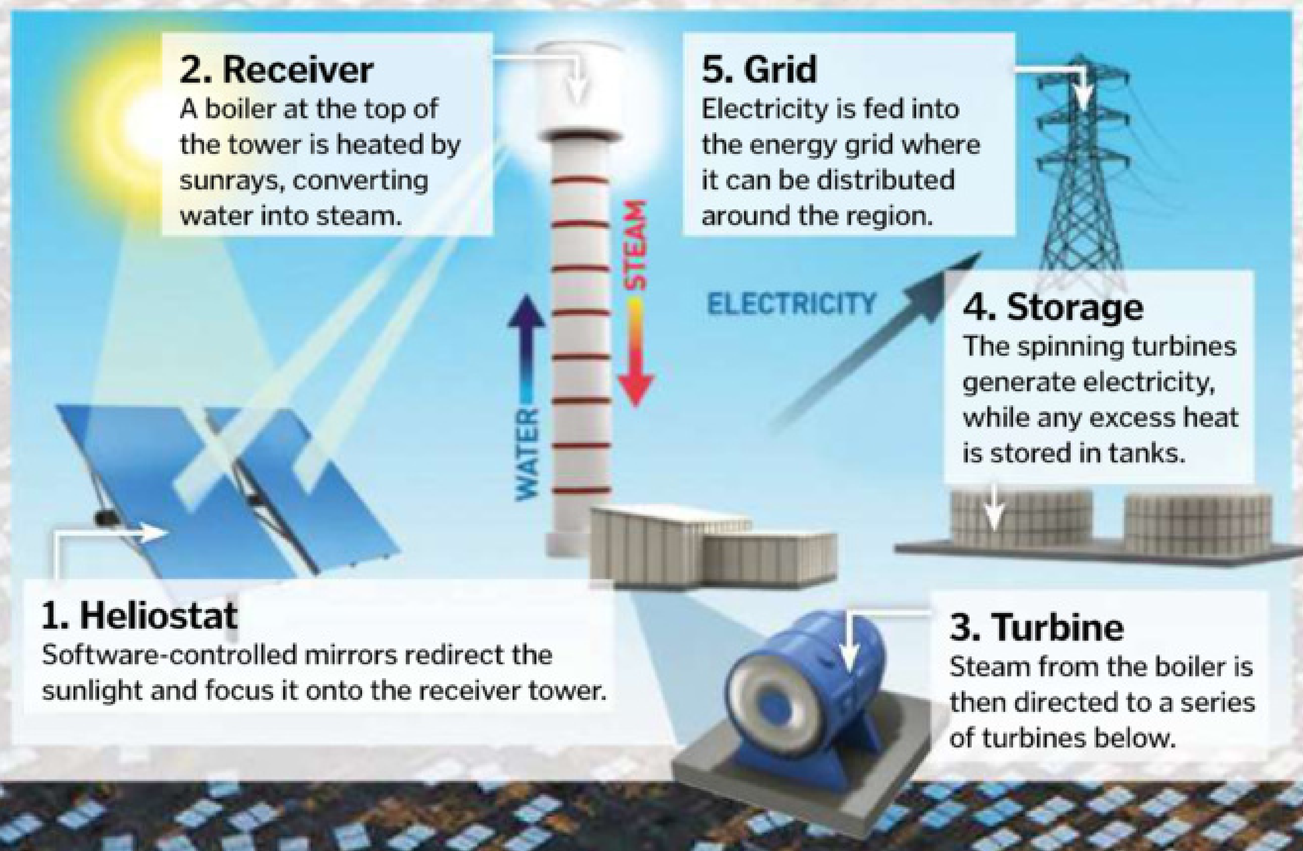
Ivanpah achieves this energy with over 170,000 Sun-tracking heliostats (mirrored panels), which receive a vast quantity of direct sunlight over the 1,415-hectare (3,500-acre) site and redirect it onto steam-producing thermal boilers mounted on top of three receiver towers. This steam is then used directly to power electricity-producing turbines (see 'Ivanpah step-by-step' below to follow the process).

Construction of the Ivanpah project began in October 2010 and it formally opened in February 2014, with the site set to contribute to California's existing electricity grid.

However, the project has been seen by some environmentalist organisations as controversial due to its construction over an established ecosystem. In particular over 200 desert tortoises needed to be relocated during the build, with a cost of $55,000 per tortoise needed for the move.

Ivanpah step-by-step

From heliostat to energy grid, how does Ivanpah deliver so much power?

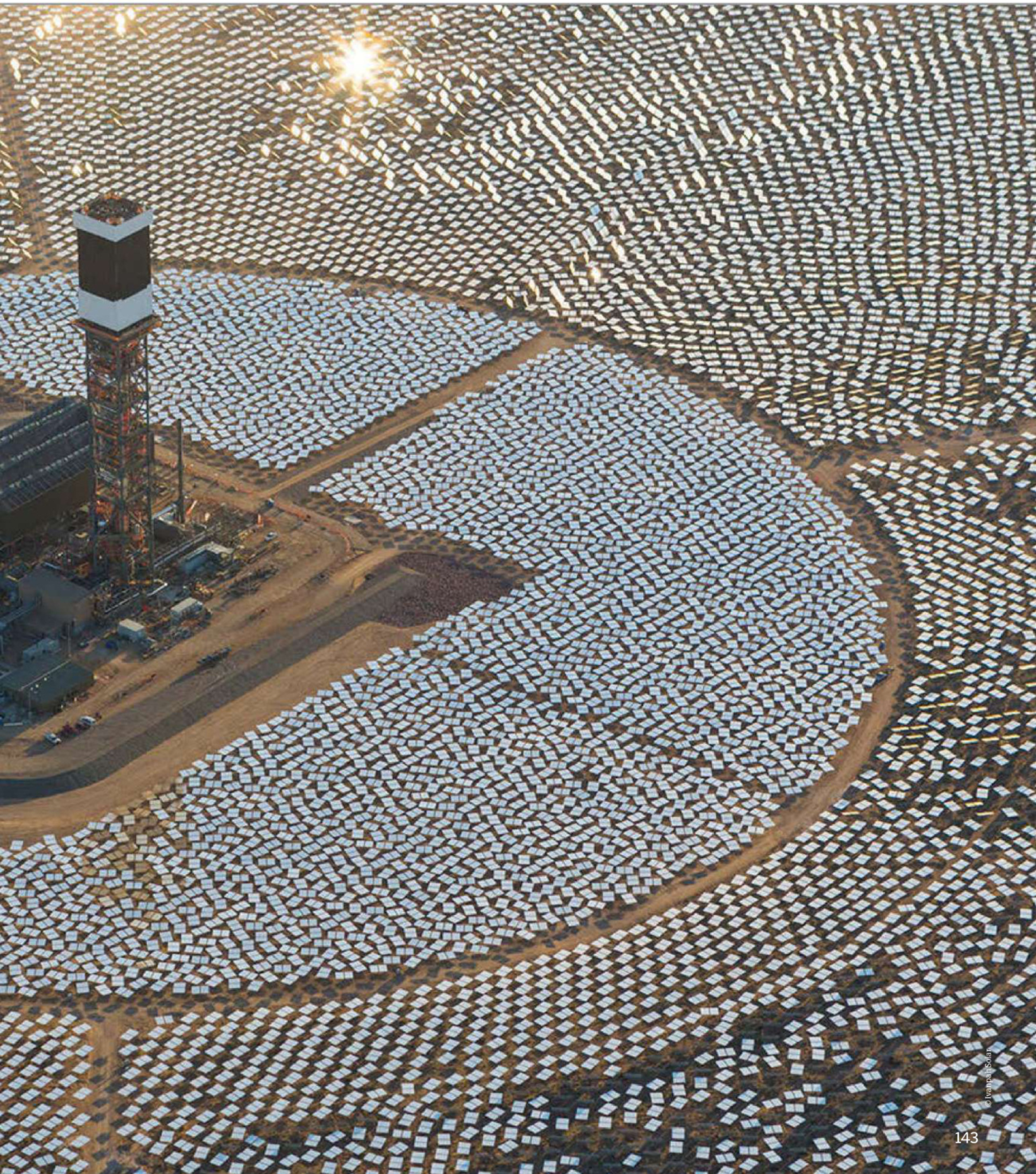


THE STATS
IVANPAH FACILITY

HELIOSTATS 173,500 | LAND AREA **14.2km²** | REDUCTION IN CO_2 (TONS/YR) 400,000

MAXIMUM CAPACITY **392MW** | ANNUAL POWER GENERATION 1,079,232MWh | THERMAL PLANTS **3**

DID YOU KNOW? *The Ivanpah Solar Power Facility cost in the region of £1.4 billion ($2.2 billion) to build*



© Wandel Scan

Secrets of the synchrotron

Find out how the UK's largest laboratory can accelerate electrons to nearly the speed of light

Electromagnetic (EM) radiation is incredibly useful. It enables us to transmit music wirelessly over large distances, cook food in our microwaves and see the world around us in vivid detail. However, now more than ever, electromagnetic radiation is also crucial in studying the physical, environmental and life sciences that are making real breakthroughs for people on a day-to-day basis. From the creation of new drugs and vaccines, through to the testing of revolutionary artificial organs and on to discoveries that allow diseases to be prevented, the harnessing of EM radiation on a large scale is truly expanding horizons in the scientific world.

In the UK, that revolution is happening at the Diamond Light Source national synchrotron facility in Oxfordshire. A high-tech particle accelerator that excels in generating vast quantities of EM radiation in the form of synchrotron light. We decided to take a trip to this cutting-edge science site to see what working there is like on an average day as well as what ground-breaking experiments are currently being investigated...

Exploring the synchrotron

A good place to start would be to explain what a synchrotron actually is. Essentially it's a large, complex system of machines that generates electrons, accelerates those electrons to near light speed and then deposits them in a large storage ring. The high-energy electrons then fly around the ring circuit continuously until they are manipulated to generate very high intensity, X-ray light; we are talking about electrons with around three gigaelectronvolts (GeV), a GeV being a unit of energy equal to a billion electron volts. This is the light that scientists can utilise in their experiments.

Right now we're about to meet with Dr Guenther Rehm, head of the Diamond Synchrotron's Beamline Diagnostics Group. This is the team responsible for ensuring that when visiting scientists need X-ray light, they get it.

We step through from Rehm's office in Diamond House, a sleek, glass-walled complex in which the majority of the facility's 400 staff is based. Then once we're across the security-controlled bridge into the synchrotron facility proper, he begins to describe how the system works.

The synchrotron here consists of four main parts, the first of which is an electron gun. Sitting at the heart of the facility, this gun is responsible for generating electrons – by heating a high-voltage cathode in a vacuum – and then forcing them to bunch up together and compress into compact groups; the latter is achieved by passing the beam of electrons through a cavity where an alternating electric field is active.

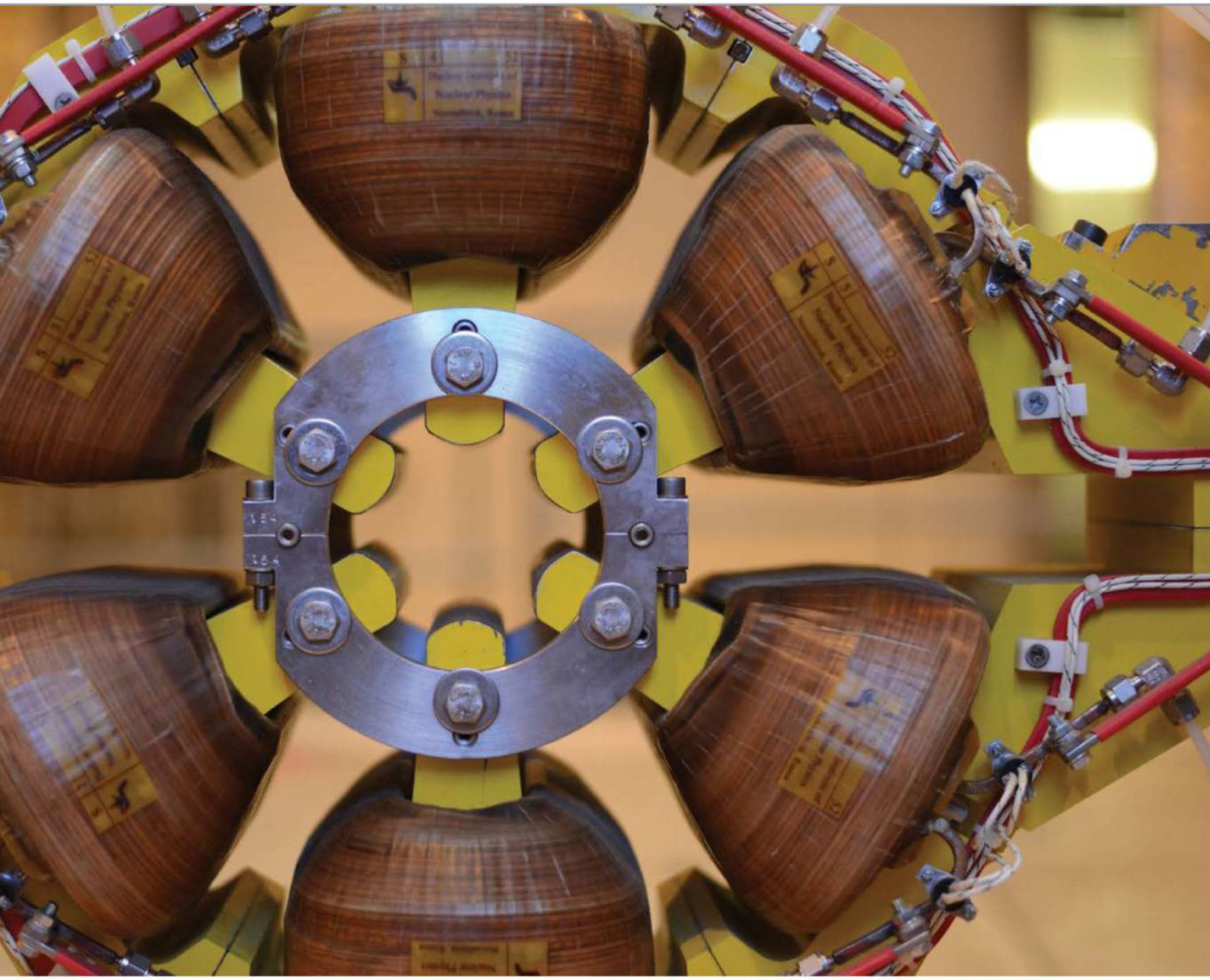
From the bunching cavity, a beam of compressed groups of electrons passes into a linear accelerator. This part of the synchrotron uses a series of electric fields to force the compressed groups of electrons in the stream to accelerate to close to the speed of light and up to a charge level of approximately 100 MeV. From here the sped-up bunches of electrons are injected into the booster synchrotron.

The booster synchrotron sits just off the linear accelerator. It is a 158m (518ft), 'O'-shaped stainless-steel tube vacuum surrounded by magnets that sits within the synchrotron's storage ring and other facilities. This smaller synchrotron receives the electrons and then, with the help of 36 dipole magnets, bends them around the vacuum circuit while they are accelerated further up to the necessary extraction energy of three GeV. Travelling at almost the speed of light and carrying an insane energy level, the electron bunches are lastly injected into the synchrotron's storage ring.

The storage ring is similar in both build and purpose to the booster ring, but on a far larger scale. The storage ring consists of a vacuum in which the charged electrons travel, a series of magnets including dipole-bending magnets to manoeuvre the beam around the circuit, quadrupole and sextupole magnets to ensure accurate beam focus

One of the synchrotron's sextupole magnets. These are responsible for achromatic correction and maintenance of a stable electron orbit within the facility's storage ring

DID YOU KNOW? *By 2018, the Diamond synchrotron will boast 32 beamlines*



The Diamond synchrotron is located near the city of Oxford in the UK. Its advanced technology attracts scientists from all over the world

and position, as well as special magnets called insertion devices (IDs) to manipulate electrons for synchrotron light production.

The IDs are the real stars of the synchrotron, capable of forcing passing electrons to oscillate around their straight course. As a result of their resistance, super-powerful X-rays are produced. As such, prior to any beamline – offshoots from the ring where experiments take place – you'll find an ID. The electrons enter the device, oscillate, create X-rays and then, while the electrons are flung farther down the storage ring by dipole magnets, photons continue straight, down the beamline for use in experiments.

Staying in control

Next we arrive at beamline central control. A large spacious room overlooking approximately a third of the expanding facility, the area is filled with a main bank of monitors, two members of the diagnostics team manning computer systems. Rehm explains that the day-to-day operation of the synchrotron is heavily automated, hence the minimal staffing. However, due to the incredible complexity of the systems involved in creating and maintaining high-energy electron beams, the status of the complex has to be constantly monitored. Indeed, we had expected that controlling an electron beam of such magnitude would be no easy feat.

At all times the beam in the storage ring at the synchrotron is analysed within the control room for charge level, position, time structure and electron losses. This is done through a piece of software referred to as EPICS: Experimental Physics and Industrial Control System. This allows the invisible beam's properties to be visualised via a variety of sensors, monitors and cameras within the ring.

In a demonstration of how this works, Rehm shows how over a ten-minute period the bunched electrons in the storage ring suffer inevitable loss. This is due to collisions and residual gas molecules, as well as energy loss through the generation of synchrotron light by the insertion devices and bending by the dipole magnets. To maintain optimal beam stability and synchrotron light quality, it is automatically topped up periodically. Watching a live graph in EPICS, we see how the overall charge level drops within the ring and then, precisely after ten minutes, returns back to its start level.

Rehm explains that not only is this topping up automatic, but the system can actually target the parts of the beam in which the electrons have

Diagnostics centre
The synchrotron's operation is controlled and monitored from a central control room. Despite many systems being automated, the room is permanently staffed in case of a serious error.

Control cabin
This is the final hutch of each beamline and is where the scientific teams monitor and control their experiments and equipment.

IDs up close

Insertion devices (IDs) are arrays of incredibly strong magnets lined up in two rows – top and bottom – next to each other in tight lines that have very strong magnetic fields. The magnets are arranged to generate a specific pattern of vertical alternating magnetic field that, when electrons pass through it, causes them to oscillate (vibrate back and forth). This oscillating motion generates synchrotron radiation/light in the form of photons, which can then be siphoned off for various different experiments in synchrotron facilities.

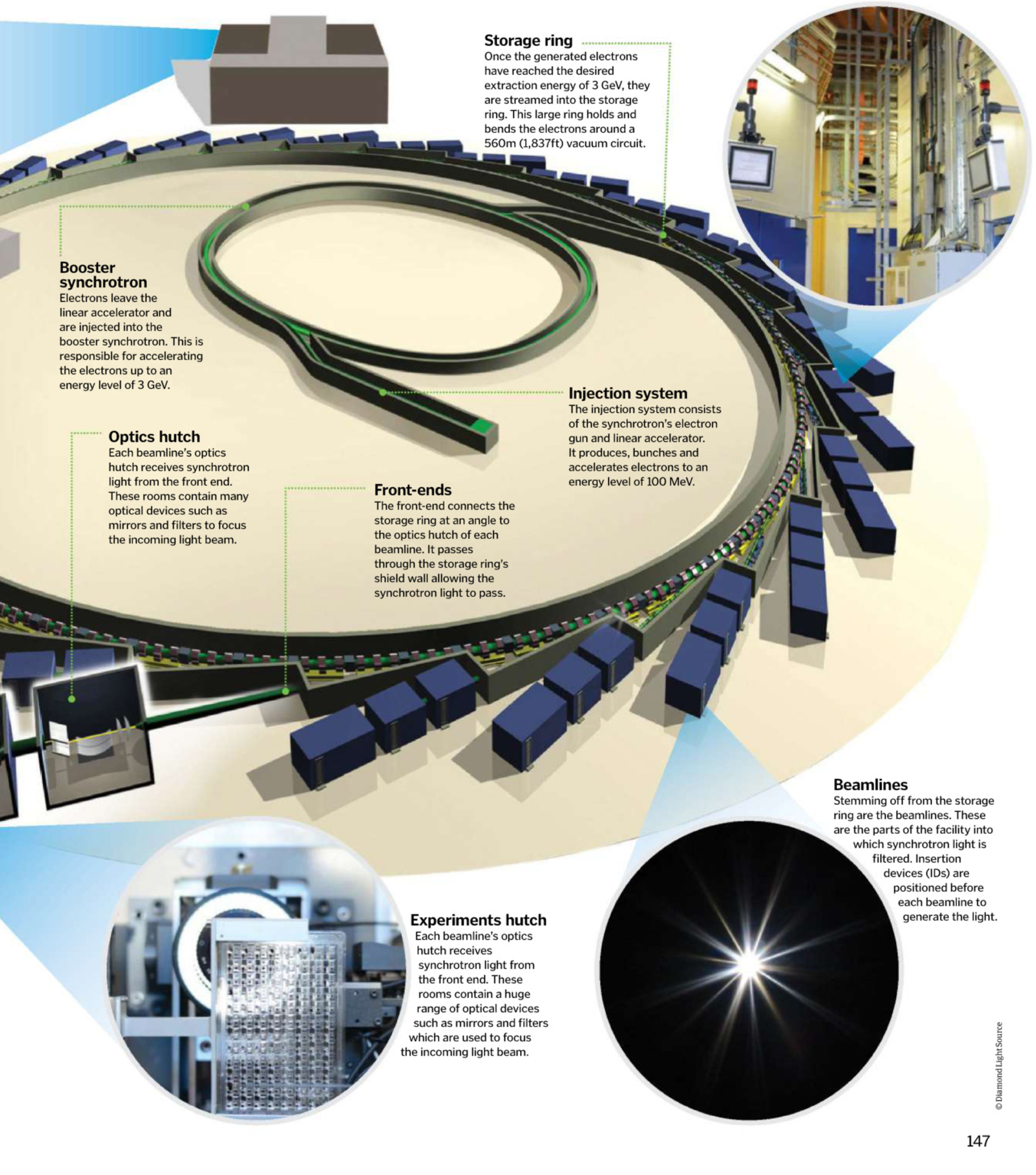
RECORD BREAKERS
ELECTRONS

300,556

KILOMETRES ELECTRONS TRAVEL

Electrons in the synchrotron's storage ring complete a circuit in just 2-millionths of a second, that's the equivalent of travelling around the Earth's equator 7.5 times, a distance of 300,556km.

DID YOU KNOW? *The storage ring is actually not a circle, but a 24-sided polygon*



Storage ring

Once the generated electrons have reached the desired extraction energy of 3 GeV, they are streamed into the storage ring. This large ring holds and bends the electrons around a 560m (1,837ft) vacuum circuit.

Booster synchrotron

Electrons leave the linear accelerator and are injected into the booster synchrotron. This is responsible for accelerating the electrons up to an energy level of 3 GeV.

Injection system

The injection system consists of the synchrotron's electron gun and linear accelerator. It produces, bunches and accelerates electrons to an energy level of 100 MeV.

Optics hutch

Each beamline's optics hutch receives synchrotron light from the front end. These rooms contain many optical devices such as mirrors and filters to focus the incoming light beam.

Front-ends

The front-end connects the storage ring at an angle to the optics hutch of each beamline. It passes through the storage ring's shield wall allowing the synchrotron light to pass.

Beamlines

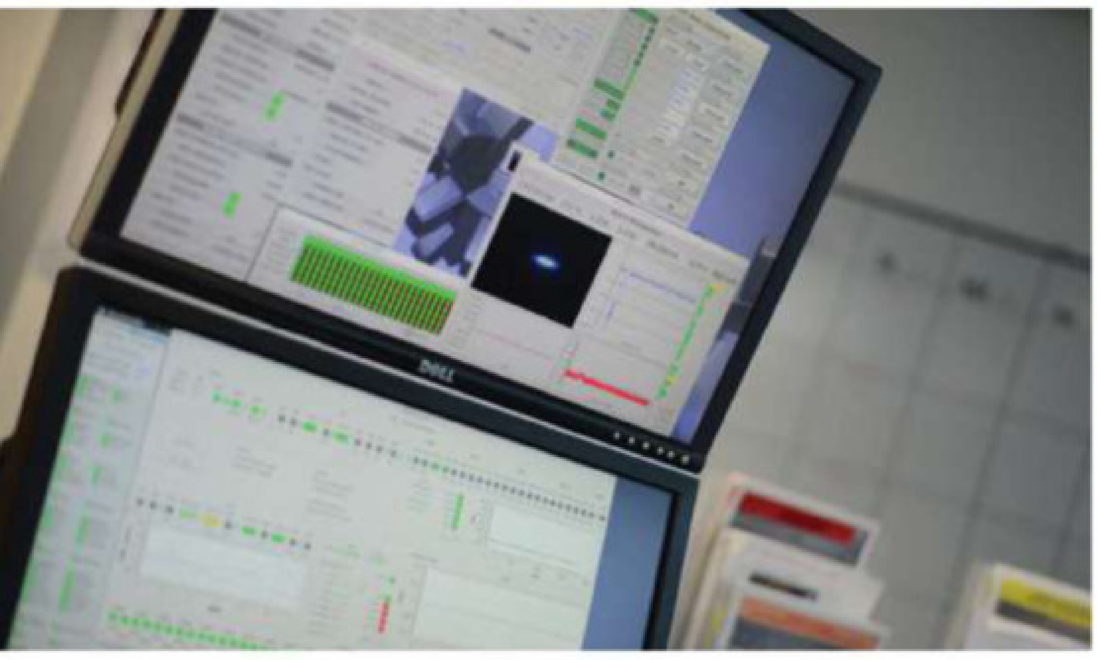
Stemming off from the storage ring are the beamlines. These are the parts of the facility into which synchrotron light is filtered. Insertion devices (IDs) are positioned before each beamline to generate the light.

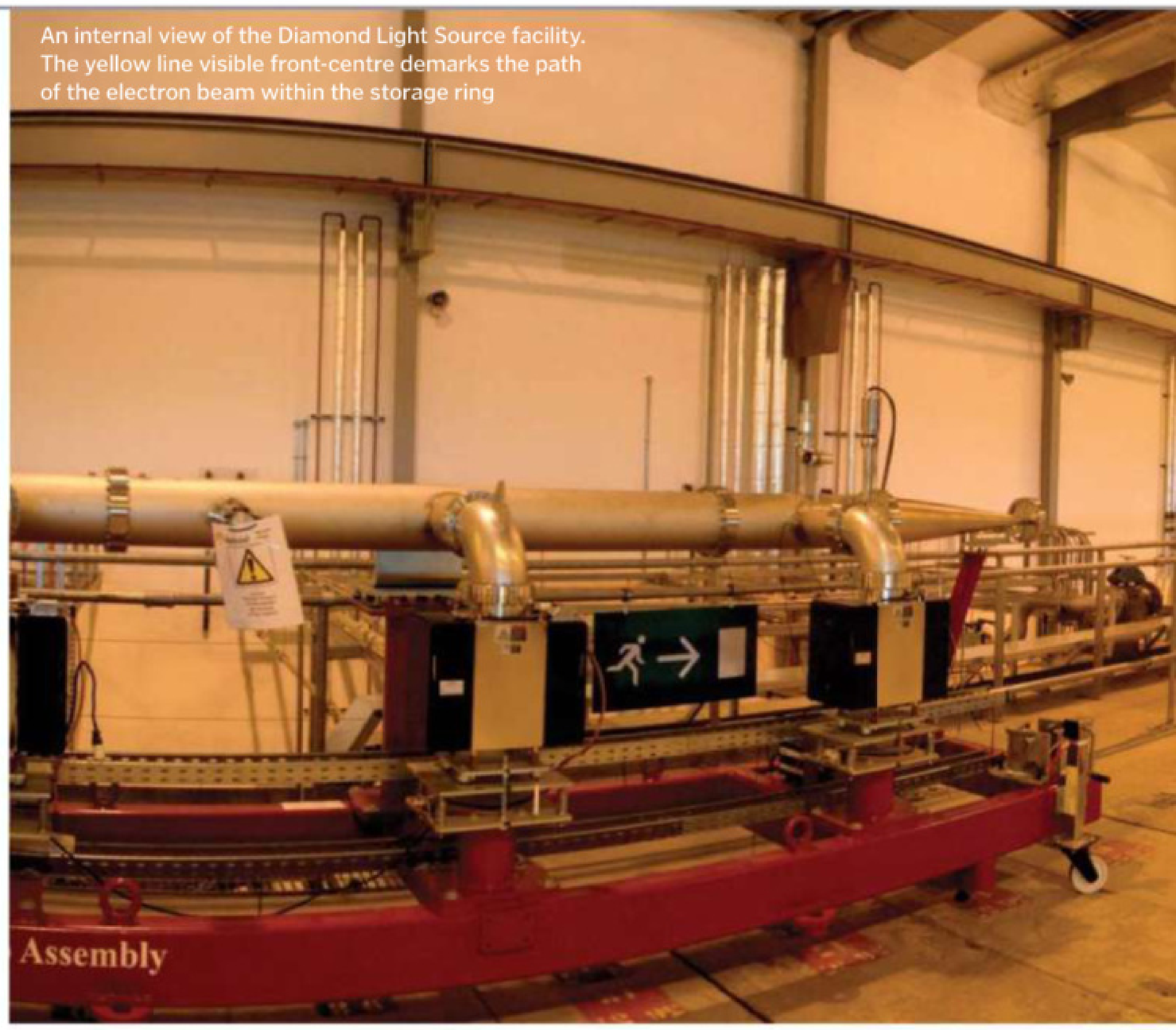
Experiments hutch

Each beamline's optics hutch receives synchrotron light from the front end. These rooms contain a huge range of optical devices such as mirrors and filters which are used to focus the incoming light beam.

© Diamond Light Source

The synchrotron





An internal view of the Diamond Light Source facility. The yellow line visible front-centre demarks the path of the electron beam within the storage ring

been lost from; this makes for an even, stable distribution of energy around the ring for light generation at all times. This system is truly amazing, capable of injecting additional electrons into the depleted electron bunches smoothly as they fly around the storage ring at almost light speed.

Looking down the beamline

Moving to the heart of the facility, we enter the cavernous main room of the synchrotron. Standing on an elevated gantry bridge, stretching out to both sides, the curved expanses reveal many of the synchrotron's individual beamlines, branching off from a concrete ring. Rehm explains that this is the facility's storage ring, albeit encased within metre-thick, radiation-blocking concrete shielding. On top of the concrete ring is a yellow line – this identifies the actual path of the electron beam inside. According to our guide, a person could lie on top of the concrete for an entire year and only receive a radiation increase of approximately 50 per cent over that from standard background radiation. Simply put, very little radiation escapes the ring.

As we progress to get a better look at the storage ring and beamlines, Rehm begins to tell us about a major challenge of his occupation: consistency of run time.

Despite the synchrotron having a day's downtime every week for maintenance, trying to keep all the various systems and subsystems working together continuously without failure is challenging. Scientists are visiting the facility 24/7 and spend months applying and waiting for their chance to use a beamline, so any unscheduled downtime is keenly felt.

It is some of those scientists that How It Works is about to meet, but first Rehm has one more stop. Sandwiched between two beamlines is a small, black room. On entering, we find a large table stuffed with machines, pipes, optics and cabling. Behind this, a small hole is cut in the wall. This is the Optics Diagnostics Cabin and it allows the support scientists to explore the temporal structure of the stored electron beam, revealing its fill pattern (how much charge is in each of the electron bunches). Rehm holds his hand in front on the incoming beam of light to reveal its apparent weakness, like a faint splodge. We then look down the incoming beam and are immediately dazzled by a piercing bright light. This is but a minuscule replica of the high-energy synchrotron light in the beamlines.

Handling the light

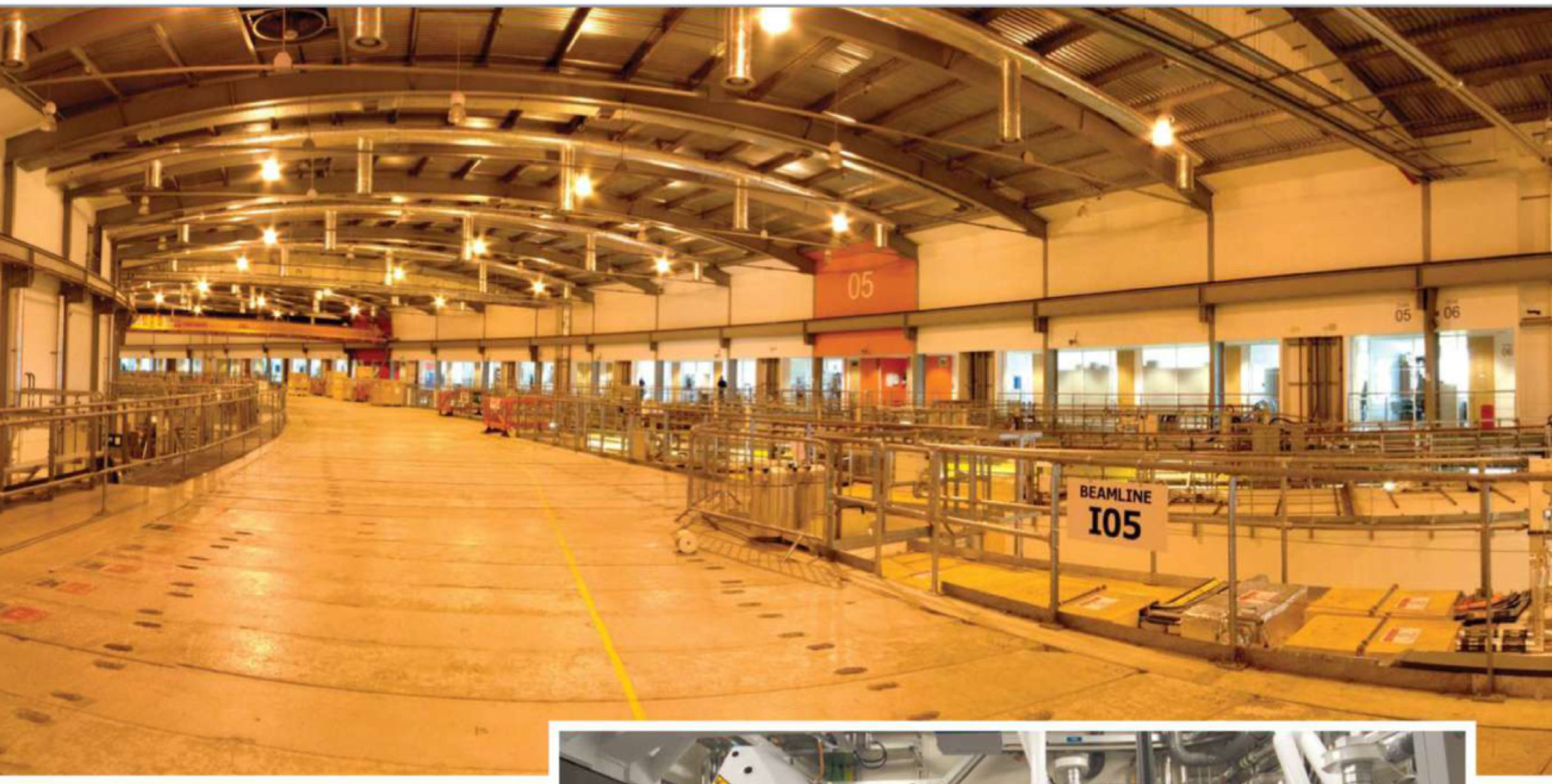
Knowing how the synchrotron works is one thing, but what does it actually mean for the world at large? Enter Professor Nick Terrill, the principal beamline scientist for the small angle scattering and diffraction beamline (I22). Among many other examples, Terrill described how a team recently had used I22 to test new polymer-material artificial heart valves. The team built a tiny device to stretch the valve to reproduce the effects of a heart beat and then used the synchrotron's high-energy X-ray light source to image the internal structure of the polymer valve in continuous resolution over a long period. It is hoped these sort of polymer valves could soon replace the problematic mechanical and animal implant valves currently used.

After a short walk around the synchrotron's outer walkway to beamline I24, we come across the microfocus macromolecular crystallography station. I24 is staffed by Diamond's senior support scientist, Dr Danny Axford, who explains how the team is working on membrane proteins, exploring their structures –something of vital importance in the creation of new drugs among other applications. This project is a collaboration between Imperial College London and Diamond itself. It is making use of both the on-site Membrane Protein Lab, which negates the need to transport samples and potentially damage them, as well as a new technique in

THE STATS
SYNCHROTRON

AREA OF FACILITY 43,300m²
STORAGE RING SIZE **562m**
COST TO BUILD £260mn
STORAGE RING BENDING MAGNETS **48**
CURRENT NUMBER OF BEAMLINES 22
ELECTRON BEAM CHARGE **3 GeV**

DID YOU KNOW? *Over 400 people work at the Diamond synchrotron facility*

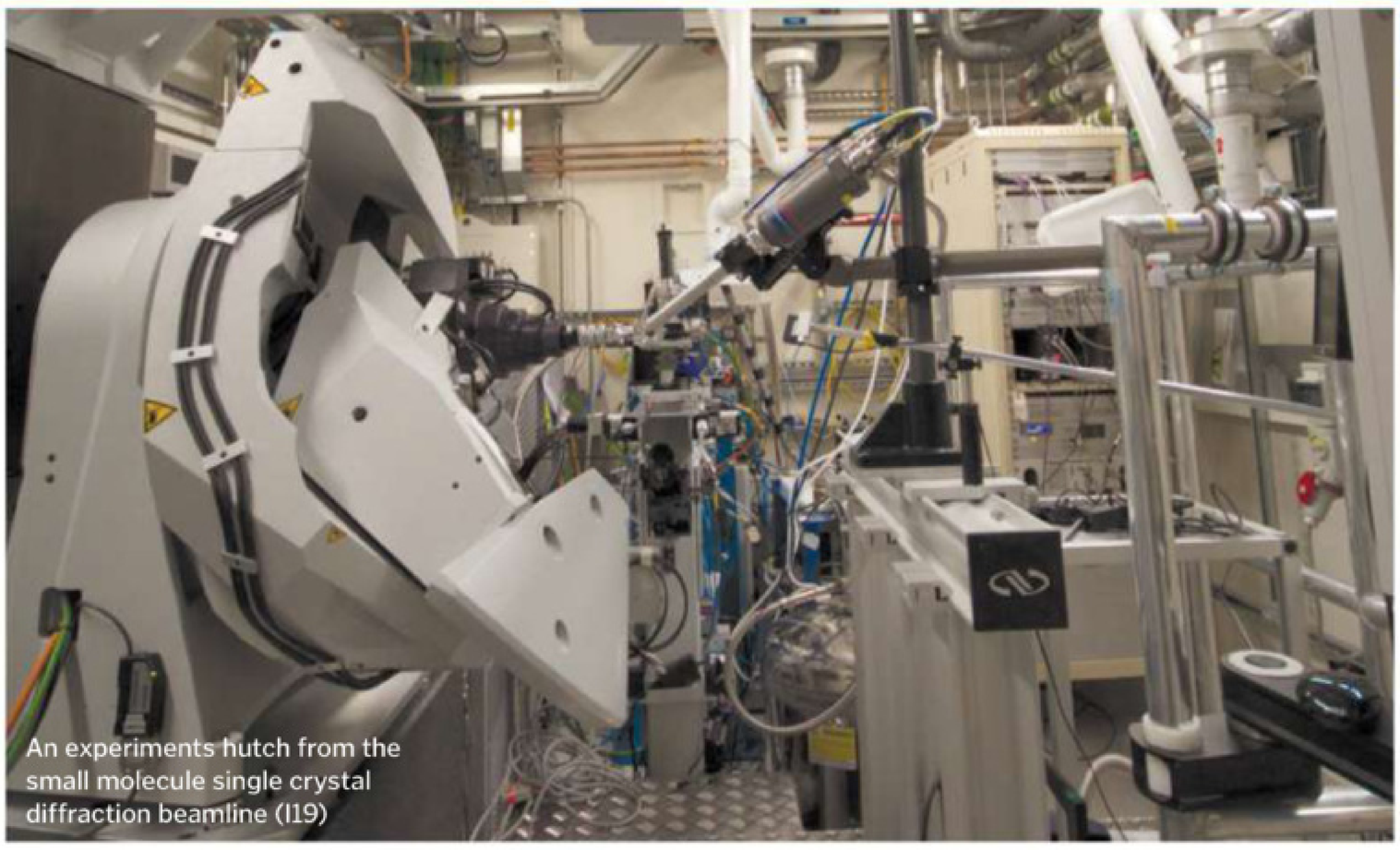


which a wide variety of crystal samples can be imaged in a short space of time.

After allowing the visiting scientists to finish analysing their current batch of samples, Axford opens up I24's experiment's hutch – the room containing the liquid-nitrogen storage tanks, imaging sensor, robotic arm, synchrotron light-focus optic and sample array all needed to perform experiments. The sensor in this room is state of the art and, alongside the sample-holding array, allows rows of crystals to be imaged at room temperature. This is incredibly useful as heat from the imaging process damages crystals, so capturing their structure quickly is crucial – hence why many samples are cryogenically cooled.

Our next port of call is the small molecule single crystal diffraction beamline (I19), where we see how a variety of crystallised samples are being analysed through diffraction techniques with samples ranging in areas from cancer to hydrogen storage. Next door, in I20, we get a detailed tour of the impressive versatile X-ray absorption spectroscopy beamline by principal beamline scientist Dr Sofia Diaz-Moreno.

This beamline, which is much larger than any of the others, has two experiment hutches that share the line to enable different types of spectroscopy analysis. What really excites us is hearing about how important chemical components in catalysts – even in very low concentrations – can have their structure illuminated and imaged continuously. This ability to image reaction processes at an atomic level and at microsecond time scales is truly mind-blowing, and is allowing scientists to understand things like catalysts, metalloproteins (metal ion-containing proteins) and toxic materials like never before.


An experiments hutch from the small molecule single crystal diffraction beamline (I19)

Racing the electron beam

After witnessing first hand just how this impressive facility is enabling scientists to make radical breakthroughs in many fields of science, we have time for one final stop: a stroll on the roof of the storage ring. Ascending back up to the first floor from beamline level and crossing the metal gantry towards the centre of the facility, we break off and step directly on top of the concrete roof of the storage ring, before following the yellow beamline marker around the facility. It takes us close to ten minutes to make a full circuit around the ring; by way of comparison it takes the hyper-charged electrons beneath our feet just 2-millionths of a second.

BIOTECH

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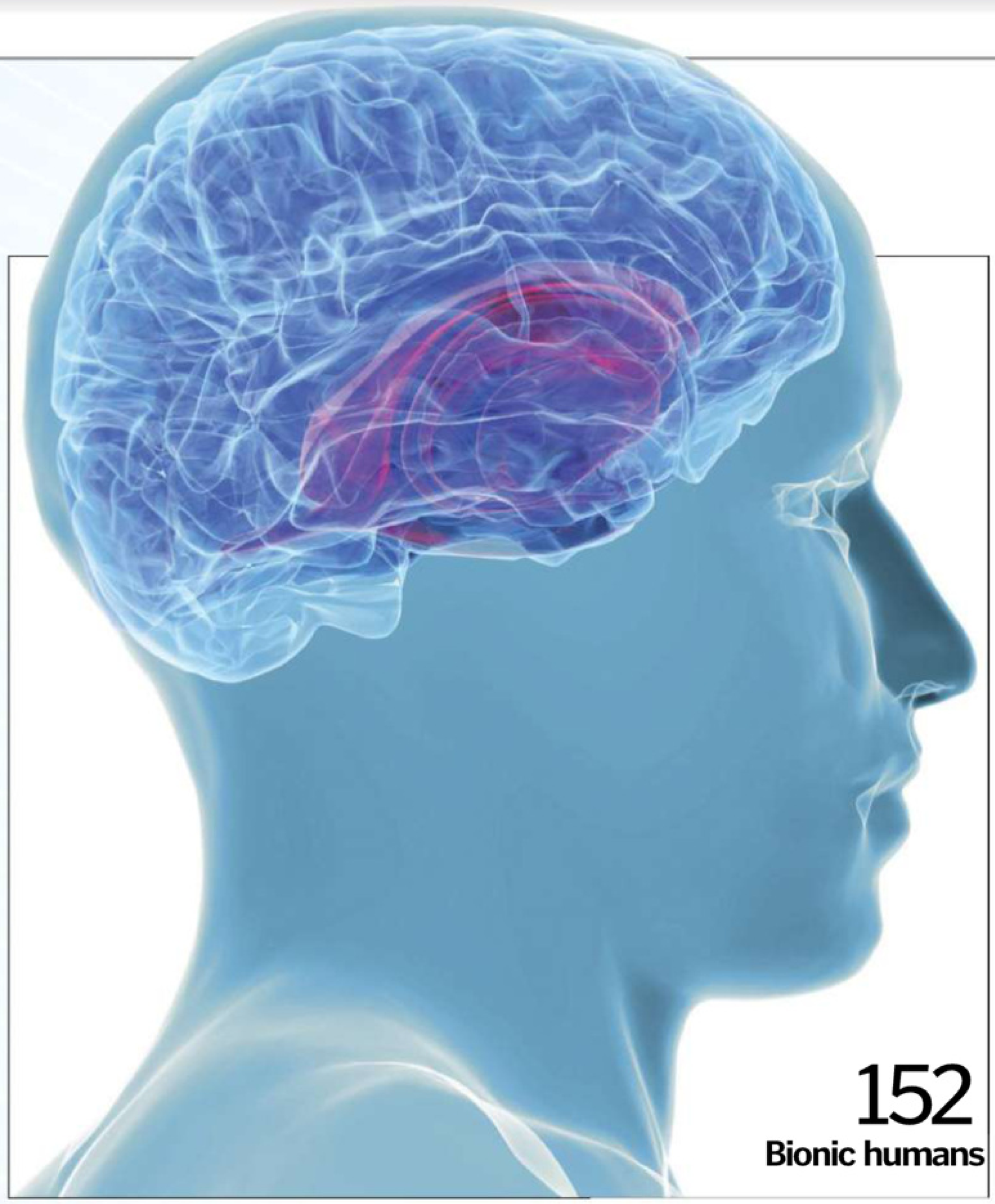

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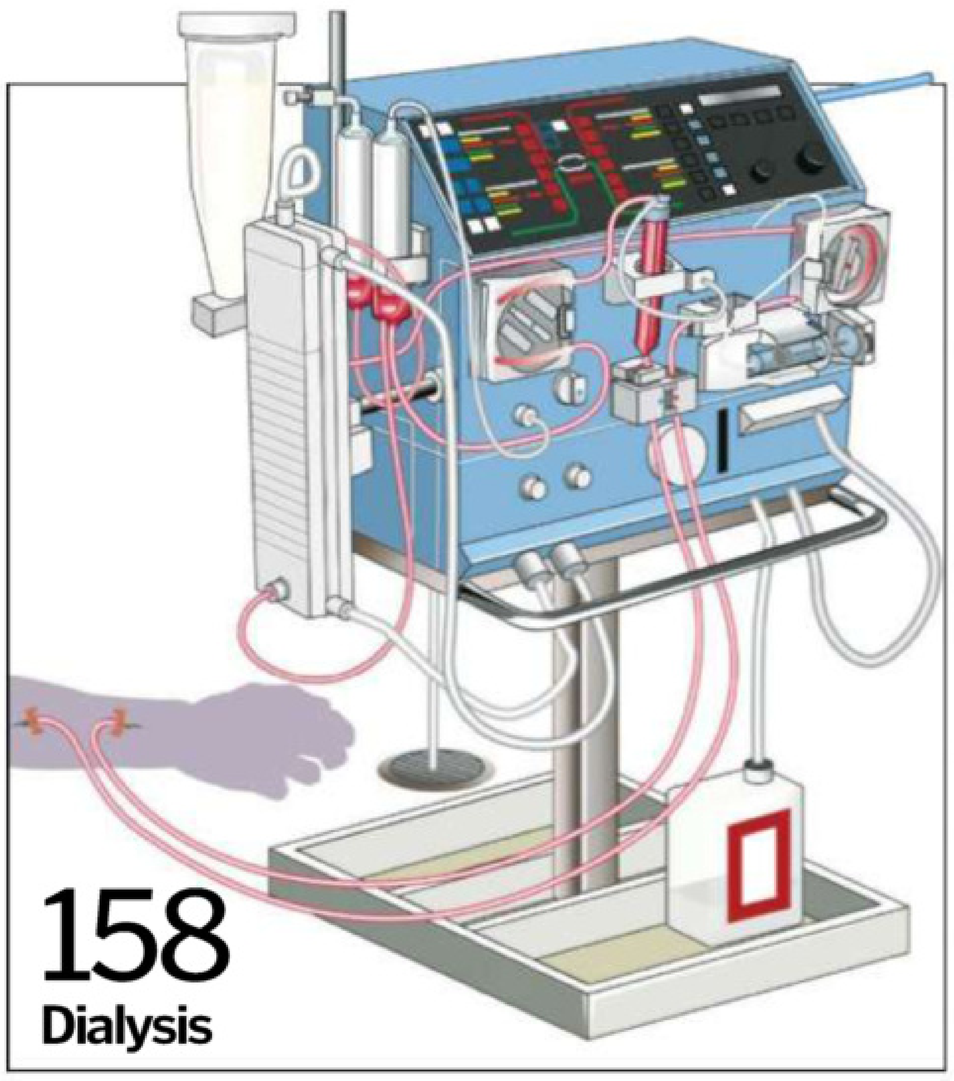

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BIONIC HUMANS

Discover the medical technology that really could make us better, faster, stronger...

Bionics experts attempt to build mechanical and electronic devices to mimic biological functions. With the exception of the brain, the human body can essentially be broken down and rebuilt using a combination of mechanical, electronic and biological technologies.

A bionic limb strips human biology back to its constituent parts. Tough materials like aluminium and carbon fibre replace the skeleton, motors and hydraulics move the limb, while springs replace the tendons that store and release elastic energy. A computer controls motion and wires relay electrical signals, as nerves would have done in a real limb. Users are now even able to control these limbs with their minds (see 'The power of thought').

Technology is also in development to replace individual muscles and tendons following injury. The synthetic muscles are made from a polymer gel, which expands and contracts in response to electrical currents, much like human muscle. The tendons are made from fine synthetic fibres designed to imitate the behaviour of connective tissue.

The mechanical nature of limbs makes them excellent candidates for building robotic counterparts, and the same applies to the human heart. The two ventricles, which supply blood to the body and lungs, are replaced with hydraulically powered chambers. However, it's not just the mechanical components of the human body that can be replaced; as time goes on, even parts of the complex sensory system can be re-created with technology.

Cochlear implants, for example, use a microphone to replace the ear, while retinal implants use a video camera to stand in for the human eye. The data that they capture is then processed and transformed into electrical impulses, which are delivered to the auditory or optic nerve, respectively, and then on to the brain. Bionic touch sensors are also in development. For example, the University of California, Berkeley, is developing 'eSkin' – a network of pressure sensors in a plastic web. This could even allow people to sense touch through their bionic limbs.

Replacing entire organs is one of the ongoing goals of bionic research. However, breaking each organ down and re-creating all of its specialised biological functions is challenging.

If only part of an organ is damaged, it's simpler to replace the loss of function using bionics. In type 1 diabetes, the insulin-producing beta cells of the pancreas are destroyed by the immune system. Some

STRANGE BUT TRUE

LIMB LOSS CULPRIT

What is the number one cause of limb amputation?

A Car accident B Diabetes C Lightning

Answer:
Diabetes is the leading cause of lower limb amputation. High blood sugar damages the nerves and blood vessels in the feet, which can lead to ulcers and eventually gangrene.

DID YOU KNOW? *An artificial heart implant operation costs about £80,000 ($125,000) and £11,500 ($18,000) a year to maintain*

The power of thought explained

Cutting-edge bionic limbs currently in development allow the user to control movements with their own thoughts. Technically called 'targeted muscle reinnervation' it's a groundbreaking surgical technique that rewires the nerves in an amputated limb. The remaining nerves that would have fed the missing arm and hand are rerouted into existing muscles. When the user thinks about moving their fingers, the muscles contract, and these contractions generate tiny electrical signals that can be picked up by the prosthetic.

The prosthetic is then programmed to respond to these muscle movements, taking each combination of signals and translating it into mechanical movement of the arm. Some of the most sophisticated have 100 sensors, 26 movable joints and 17 motors, all co-ordinated by a computer built into the prosthetic hand.

A scientist controls a wheelchair using a brain-machine interface

Motor cortex
This region of the brain is responsible for planning and co-ordinating movement.

Rerouted nerves
The nerves that used to feed the missing limb are rewired into existing muscles.

Sensors
Sensors pick up tiny electrical signals when the user thinks about moving.

Motors
A series of motors replace the biological function of muscles.

Joints
Joints are designed to match the natural range of human motion.

Computer
A computer in the hand of the prosthetic arm co-ordinates all the other components.

Learn more

If this bionics feature piques your interest, why not visit London's FutureFest (14-15 March 2015) where you can witness compelling talks, cutting-edge shows, technology displays and interactive performances, hearing from such speakers as the controversial Edward Snowden. For more info visit: **futurefest.org**.

patients are now fitted with an artificial pancreas: a computer worn externally, which monitors blood sugar and administers the correct dose of insulin as required.

Entire organ replacements are much more complicated, and scientists are turning back to biology to manufacture artificial organs. By combining 3D printing with stem cell research, we are now able to print cells layer by layer and build up tissues. In the future, this could lead to customised organ transplants made from the recipient's very own cells.

Advances in bionics mean that already limbs are emerging that exceed human capabilities for weight bearing and speed. That said, the sheer complexity of our internal organs and how they interact means that it is not yet possible to fully replace man with machine. But maybe it's just a matter of time...

The right materials

One of the most important factors in biomedical engineering is biocompatibility – the interaction of different materials with biological tissues.

Implanted materials are often chosen because they are 'biologically inert' and as a result they don't provoke an immune response. These can include titanium, silicone and plastics like PTFE. Artificial heart valves are often coated in a layer of mesh-like fabric made from the same plastic used for soft drink bottles – Dacron. In a biological context, the plastic mesh serves as an inert scaffold, allowing the tissue to grow over the valve, securing it in place. Some scaffolds used in implants are even biodegradable, providing temporary support to the growing tissue, before harmlessly dissolving into the body.

Bionic limbs are worn externally, so their materials are chosen for strength and flexibility as opposed to biocompatibility. Aluminium, carbon fibre and titanium are all used as structural components, providing huge mechanical strength.

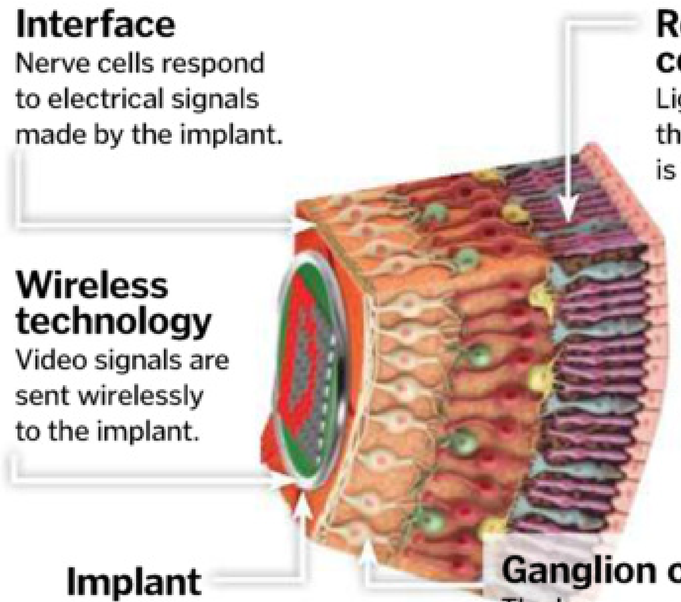
Artificial heart valves are often made from metal, such as titanium or stainless steel

Building a bionic human

Advances in technology make it possible to build limbs with components that mimic the function of the skeleton, musculature, tendons and nerves of the human body. Meanwhile, the sensory system can be replicated with microphones, cameras, pressure sensors and electrodes. Even that most vital organ, the heart, can be replaced with a hydraulic pump. Some of the newest technologies are so advanced that the components actually outperform their biological counterparts.

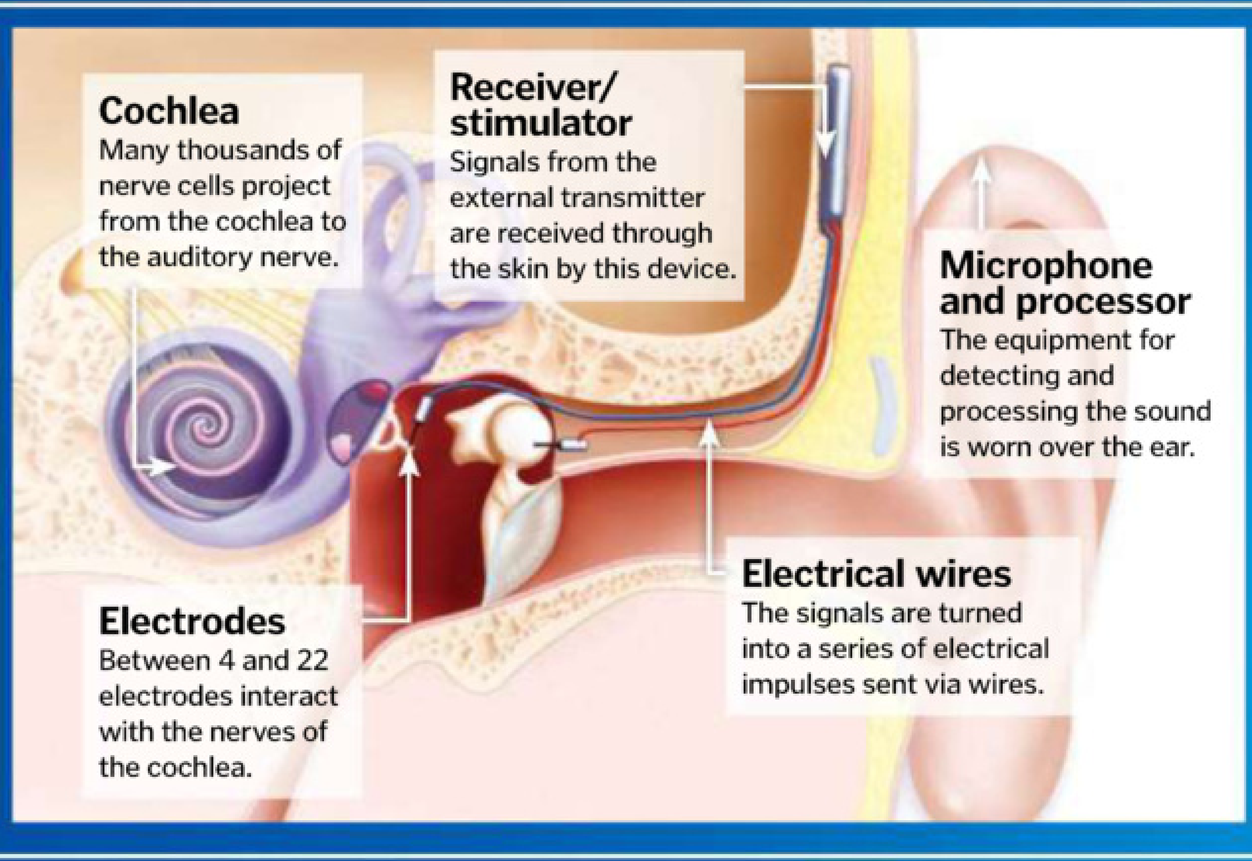
Retinal implant

Argus II, Second Sight
A camera mounted on a pair of glasses captures real-time images and transmits them wirelessly to an implant on the retina. The implant contains 60 electrodes and, depending on the image, will generate different patterns of electrical signals, which are then sent to the remaining healthy retinal cells. These cells are activated by the signals, and carry the visual information to the brain for processing.



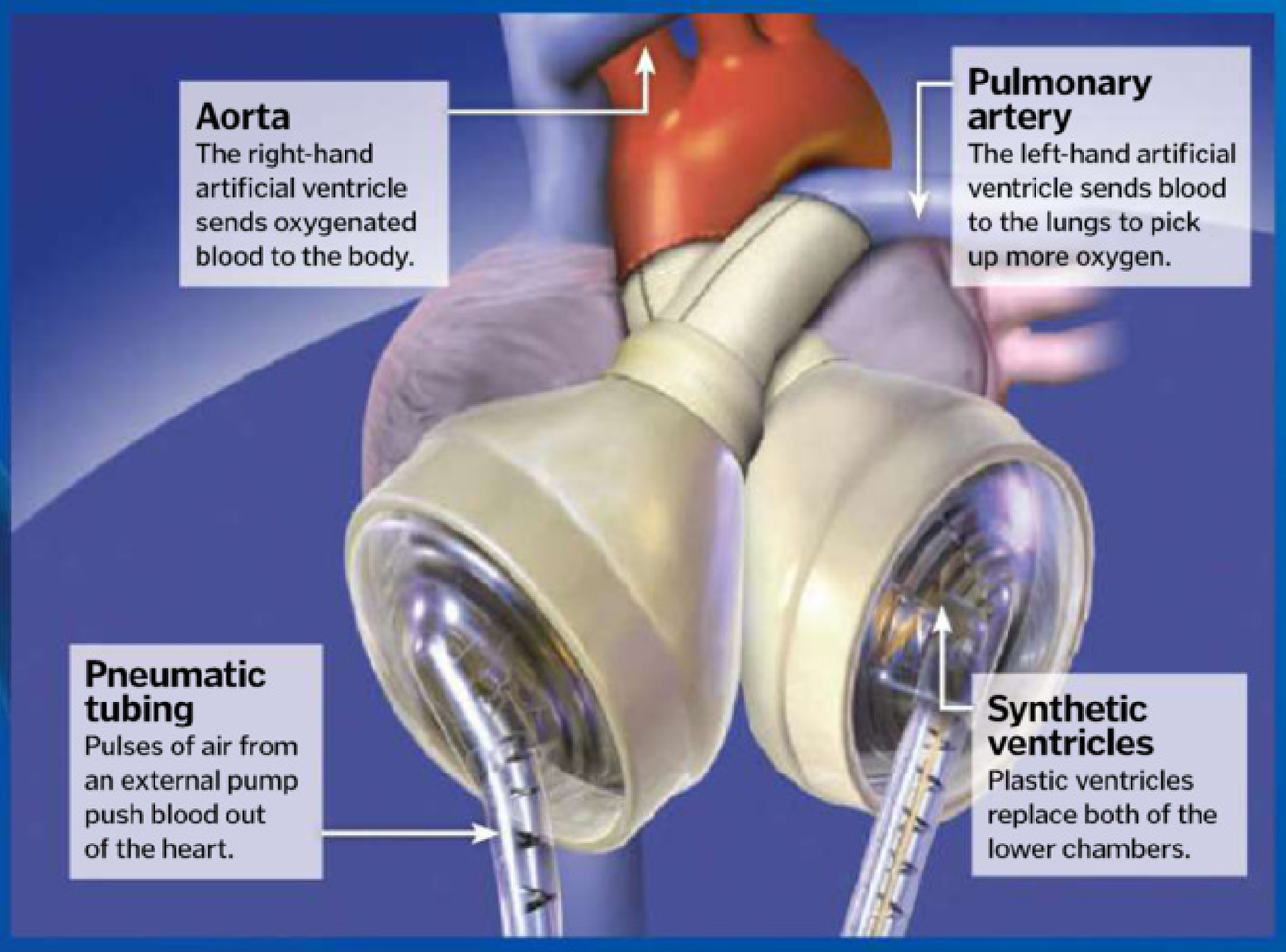
Cochlear implant

Nucleus 6, Cochlear
A cochlear implant has four main components. A microphone, worn near the ear, detects audio and transmits a signal to a sound processor. The processor then arranges the signal and sends it to a built-in transmitter. The transmitter passes the signal to an implanted receiver/stimulator, which transforms it into electrical stimuli for the electrodes. Finally these signals are relayed to the auditory nerve.



Artificial heart

Total Artificial Heart, SynCardia Systems
Plastic hearts can be implanted to replace the two ventricles of the heart. Plastic tubing is inserted to replace the valves, and two artificial chambers are also attached. The heart is then connected to a pneumatic pump worn in a backpack, which sends bursts of air to the chambers, generating the pressure that's required to pump blood around the body.



KEY DATES

BIONICS FIRSTS

500 BCE
The first known mention of a wooden prosthetic limb, worn by a prisoner after his foot was amputated.

1957
The first cochlear implant is created. Sounds are unprocessed, but it does help with lip reading.

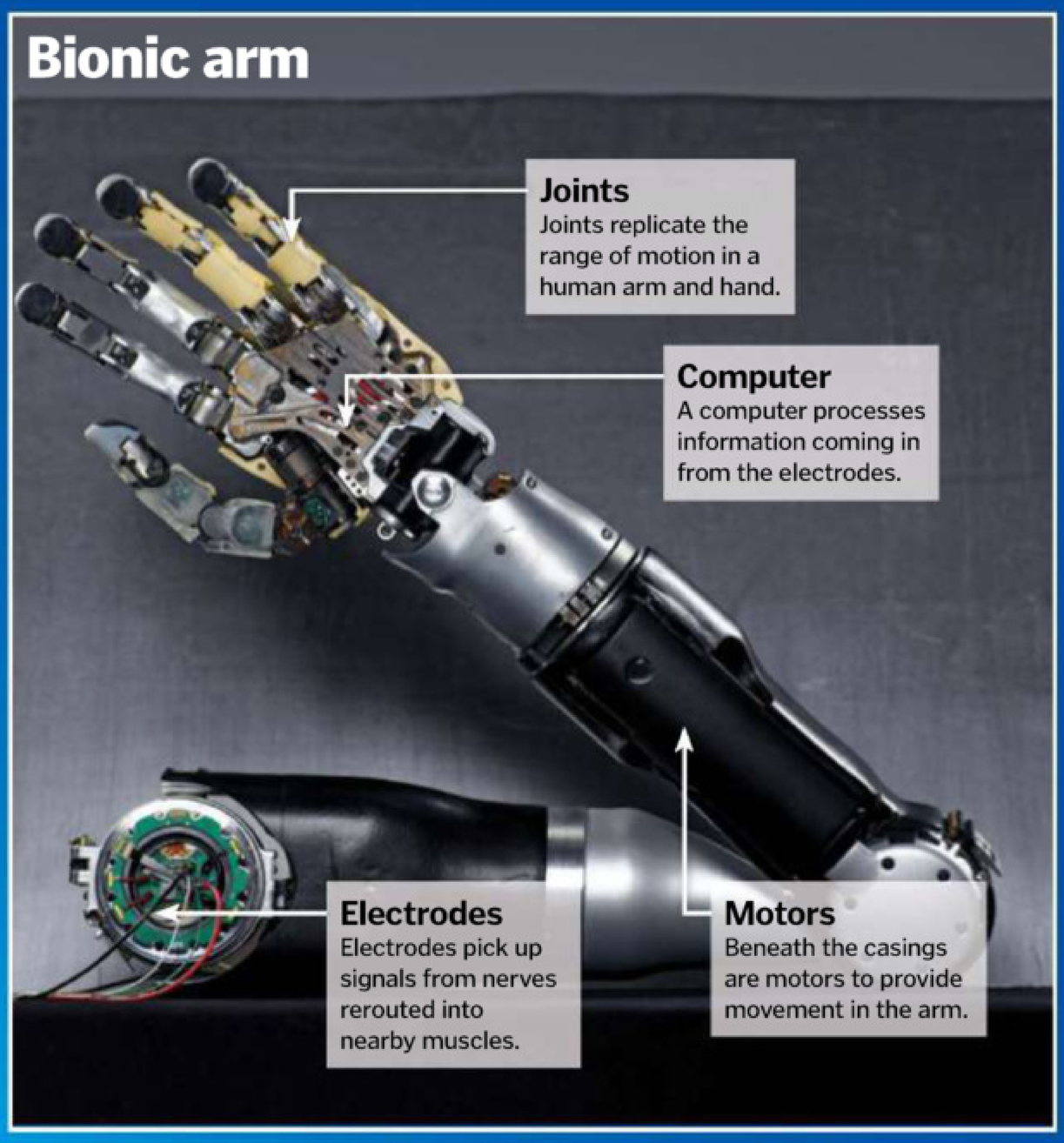
1982
The first successful artificial heart implant operation is performed at the University of Utah.

2011
The first artificial trachea transplant takes place in Sweden, using a synthetic scaffold coated in stem cells.

2013
The Argus II retinal implant is licensed, enabling patients with retinitis pigmentosa to see again.

DID YOU KNOW? *In 1812 a prosthetic arm was invented that could be moved using cables attached to the opposite shoulder*

Bionic arm



Bionic limbs

Prosthetic limbs have come on leaps and bounds in the past couple of decades. They still retain characteristic features, such as an internal skeleton for structural support and a socket to attach to the amputation site, however the most innovative models are now able to reproduce, or even exceed, biological movements. Motors are used in place of muscles, springs instead of tendons and wires instead of nerves.

The movement of many prosthetics is controlled externally, using cables attached to other parts of the body, or using a series of buttons and switches. New technology is emerging to allow the user to move the limb using their mind (see 'The power of thought'). The next logical step in this process is developing technology that enables the prosthetic limb to sense touch, and relay the information back to the user. DARPA-funded researchers have developed FINE, a flat interface nerve electrode (see below left) which brings nerves into close contact with electrodes, allowing sensory data to pass to the brain.

The future of bionics

1 3D-printed organs
Biologists are adapting the technology in order to print using living human cells. The cells are laid down in alternating layers alongside a transparent gel-like scaffold material. As the cells fuse, the scaffold disappears. For more info, go to page 168.

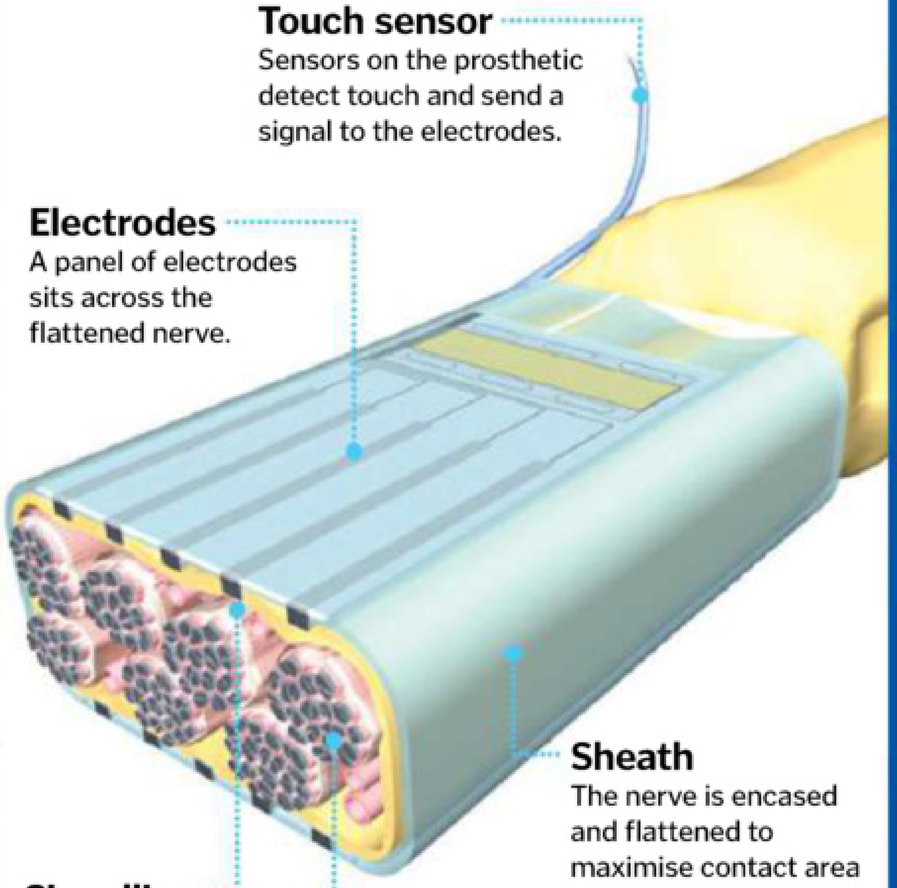
2 Ekso skeleton
Ekso Bionics has made bionic exoskeletons to allow people with lower limb paralysis to walk. Ekso supports their body and uses motion sensors to monitor gestures and then translate them into movement. Read more on page 170.

3 Artificial kidney
The University of California, San Francisco, is developing a bionic kidney. At about the size of a baseball, it contains silicone screens with nano-drilled holes to filter blood as it passes. It will also contain a population of engineered kidney cells.

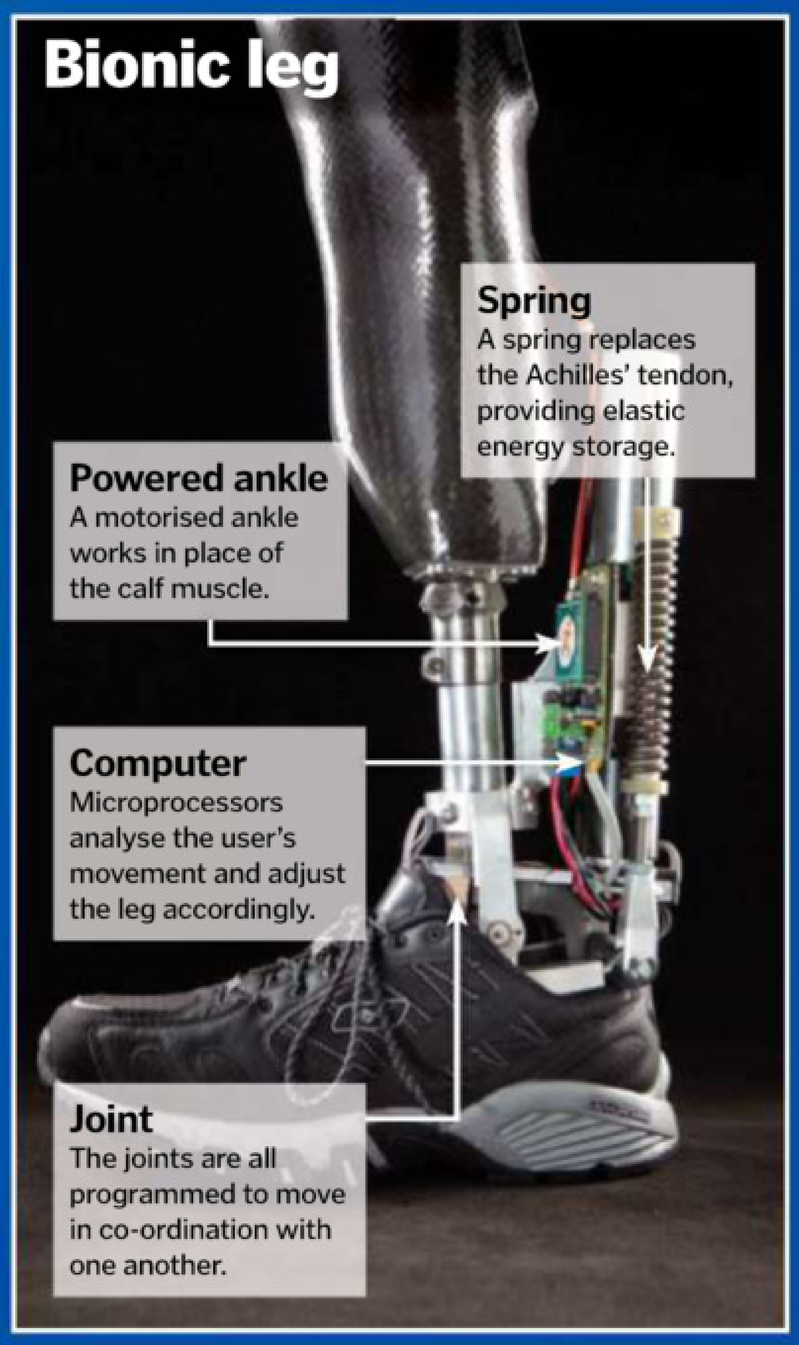
4 Man-made immunity
Leuko-polymersomes are plastic 'smart particles' that mimic cells of the immune system. They are being designed to stick to inflammatory markers in the body and could be used to target drug delivery to infections and cancer.

5 Robotic blood cells
The Institute for Molecular Manufacturing is developing nanotechnology that could increase the oxygen-carrying capacity of blood. Known as respirocytes, the cells are made atom by atom – mostly from carbon.

Touch-sensitive prosthetics



Bionic leg



© Corbis; Alamy; Thinkstock; SynCardia Systems; Getty; DARPA; Second Sight Medical Products, Inc

Medical ventilators

How these breathing machines perform their life-saving task

Breathing is one of the most natural things in the world. It's the first thing we do when we're born and we go on doing that automatically for the rest of our lives. But sometimes people need assistance with their breathing if they have respiratory issues or are under anaesthetic during an operation.

This is where the ventilator comes in. It is a machine that contains oxygen and air, which is pumped through a tube, either into your mouth or into a surgical hole in your neck, by increasing pressure in the machine, pushing the air into the lower pressure area of your lungs.

The second option is used for people who will need to be on the ventilator for longer as it is more comfortable and may allow the user to talk. The breathing tube will push air into your lungs, where it can be circulated around the body, and will also take the leftover carbon dioxide out of your body. This is called the endotracheal tube as it goes into the trachea or windpipe. It stays on your face by a strap that goes around your head. Settings on the ventilator regulate how often air is pumped into the lungs every minute, although the user can increase this if they are feeling short of breath.

The original respirator

Respirators have been around since the late 1920s when Philip Drinker and Louis Agassiz Shaw created the first widely-used negative pressure ventilator, which was more commonly known as the iron lung. It was a heavy machine, powered by vacuum cleaners and run using an electric motor. It used a pump to force air into the lungs and then draw it out again by decreasing pressure.

John Haven Emerson added a sliding tray so the user could be pushed in and out of the machine more easily, as well as windows along the side so attendants could reach in and adjust the patient. This design halved the cost of the original machine, which had been the same as a house.

Inside a ventilator

How this machine pumps essential air into your body

Breathing mask
A mask is fitted over the mouth and nose so the air cannot escape.

Breathing tube
The air is forced down the breathing tube toward the user.

Air bag
The bag inflates and deflates to show that the air is passing through the system.

Artificial breathing
The air gets pushed from the pressurised mask into your mouth, nose and travels to your lungs.

Screen
This provides a visual display of the pressure levels in the system.

Pressure change
The system increases pressure inside the machine, creating a pressure imbalance.

Return
Expelled air travels down a different tube and back into the system.

© Dreamstime; Thinkstock

The lifesaving water filter

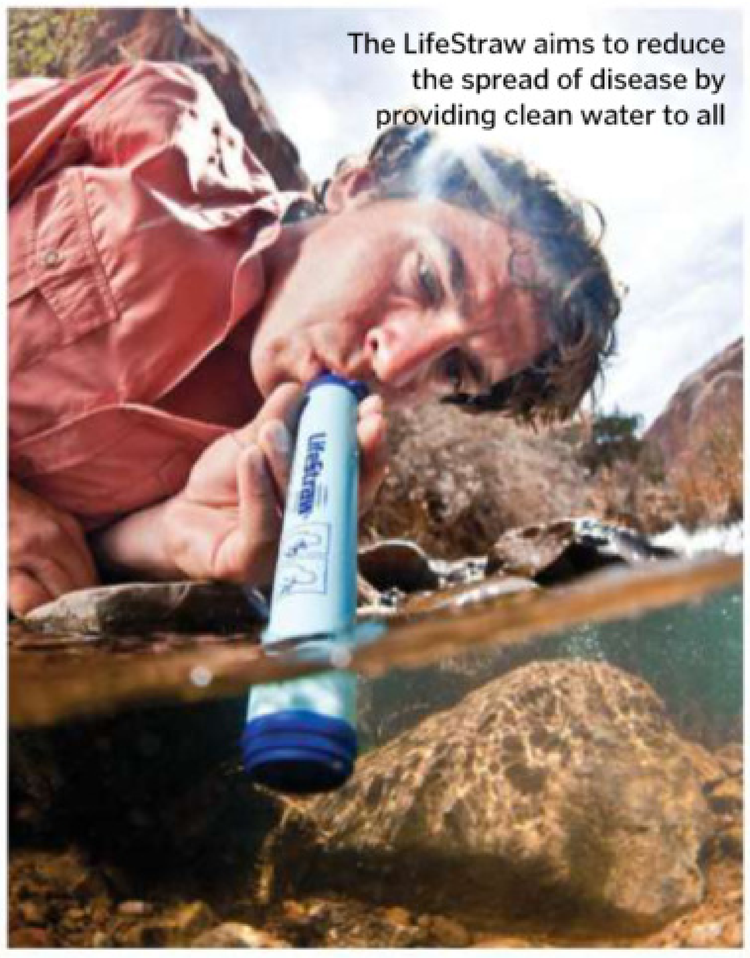
How can a simple straw make even the dirtiest water safe to drink?

Dirty water is one of the biggest killers. However, there is now a cheap and efficient way to stop dangerous, waterborne bugs in their tracks: the LifeStraw.

The device decontaminates dirty water, making it safe for human consumption. It achieves this by using a 0.2-micrometre tube with a hollow fibre membrane that allows water through, but not dirt and virtually no pathogens like parasites and bacteria, of which over 99.9 per cent are blocked.

As the latest iteration of the LifeStraw doesn't use electricity or chemicals, it's ideal for remote, impoverished areas experiencing drought or an unreliable water supply. It can process up to 1,000 litres (264 gallons).

It's already helped during the aftermath of natural disasters and mainly targets diarrhoea and Guinea worm disease: leading causes of death in developing countries.



The LifeStraw aims to reduce the spread of disease by providing clean water to all

LifeStraw up close

See what's happening inside these pocket-sized water filters

Mouthpiece
Safe water is now ready to drink. You just blow air through to clean the straw out and it's ready to use again.

Filtration
Hollow fibres in the tube trap 99.9999 per cent of bacteria and 99.9 per cent of parasites and filter out any soil particles.

Plastic casing
Weighing in at just 56g (2oz), the straw is very practical for distribution and compact enough to carry with you 24/7.

Dirty water
The potentially contaminated water is sucked up at the bottom of the device.

Intelligent fingerprinting

The tech that enables illegal substances to be detected with just a fingerprint

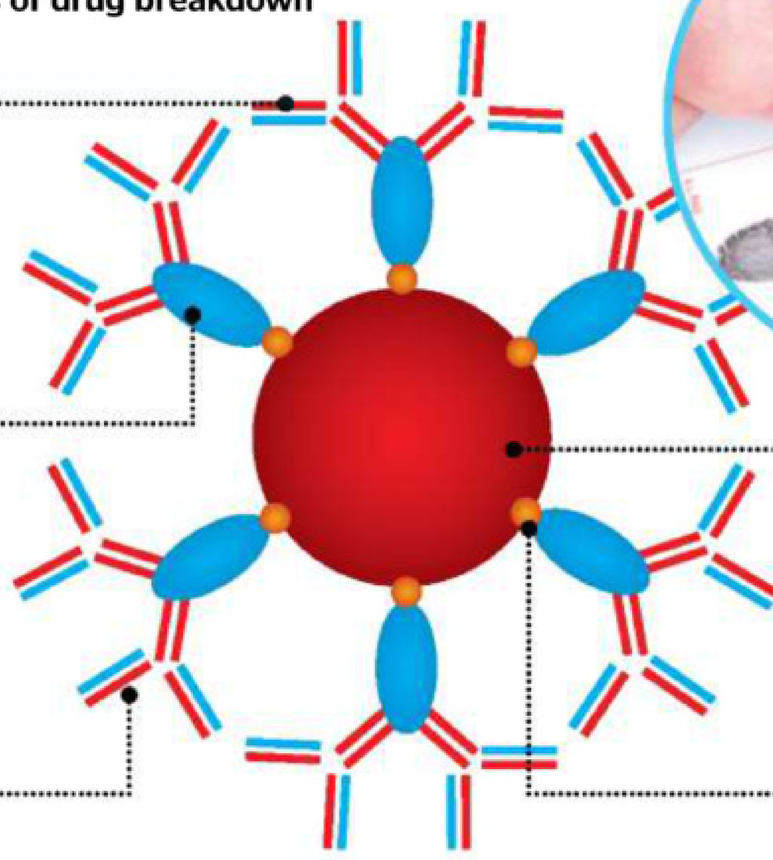
The University of East Anglia in the UK has developed a handheld device that detects the breakdown products of commonly abused drugs in sweat released from pores in the fingertips.

An image of the fingerprint is taken to create a reference point and treated with a solution containing gold nanoparticles, which stick to the breakdown products of illicit substances. The particles are stained with a fluorescent dye and a second image of the print is taken.

This test is far quicker than alternative methods and it also provides proof that a positive result belongs to the owner of the fingerprint and is not down to sample contamination. Sweat is released from pores in the fingertips and finally tracks along the fingerprint ridges, carrying with it traces of drug metabolites that gradually decrease in concentration. If the staining of the print is greatest at the pores, it provides solid evidence that the metabolites are being released from the sweat glands of the person being tested.

Nanoparticle drug testing

The test takes advantage of biology, using antibodies to detect the products of drug breakdown



Antibody
Antibodies are generated by the immune system and can be manufactured in the laboratory to stick to almost any target.

Protein
In combination with the linker molecule, proteins are used to bind the antibodies to the gold nanoparticle.

Detection
Antibodies stick specifically to the metabolites of commonly abused substances.

Gold nanoparticle
The entire complex is held together using biologically inert gold particles.

Linker
A linker molecule is used to attach the antibodies to the gold nanoparticle.

© Thinkstock; Safe-Rain Corporation

How dialysis cleans blood

Discover how the amazing dialysis process rids your body of harmful waste

When kidneys fail to filter your blood of waste and unwanted water, we rely on dialysis. An artificial process, it takes the basic scientific principles of concentration gradients and diffusion to filter out harmful substances from the bloodstream, such as extra salt and excess fluids. A dialysis machine can control which substances are removed and at what concentration, allowing fine control of waste product removal and electrolyte balance, like sodium and potassium. Dialysis is needed when the kidneys' natural function is lost. Since you can live with one kidney, both need to be affected before dialysis is required. Common reasons for dialysis are severe diabetes and long-standing high blood pressure, while rare causes include genetic diseases.

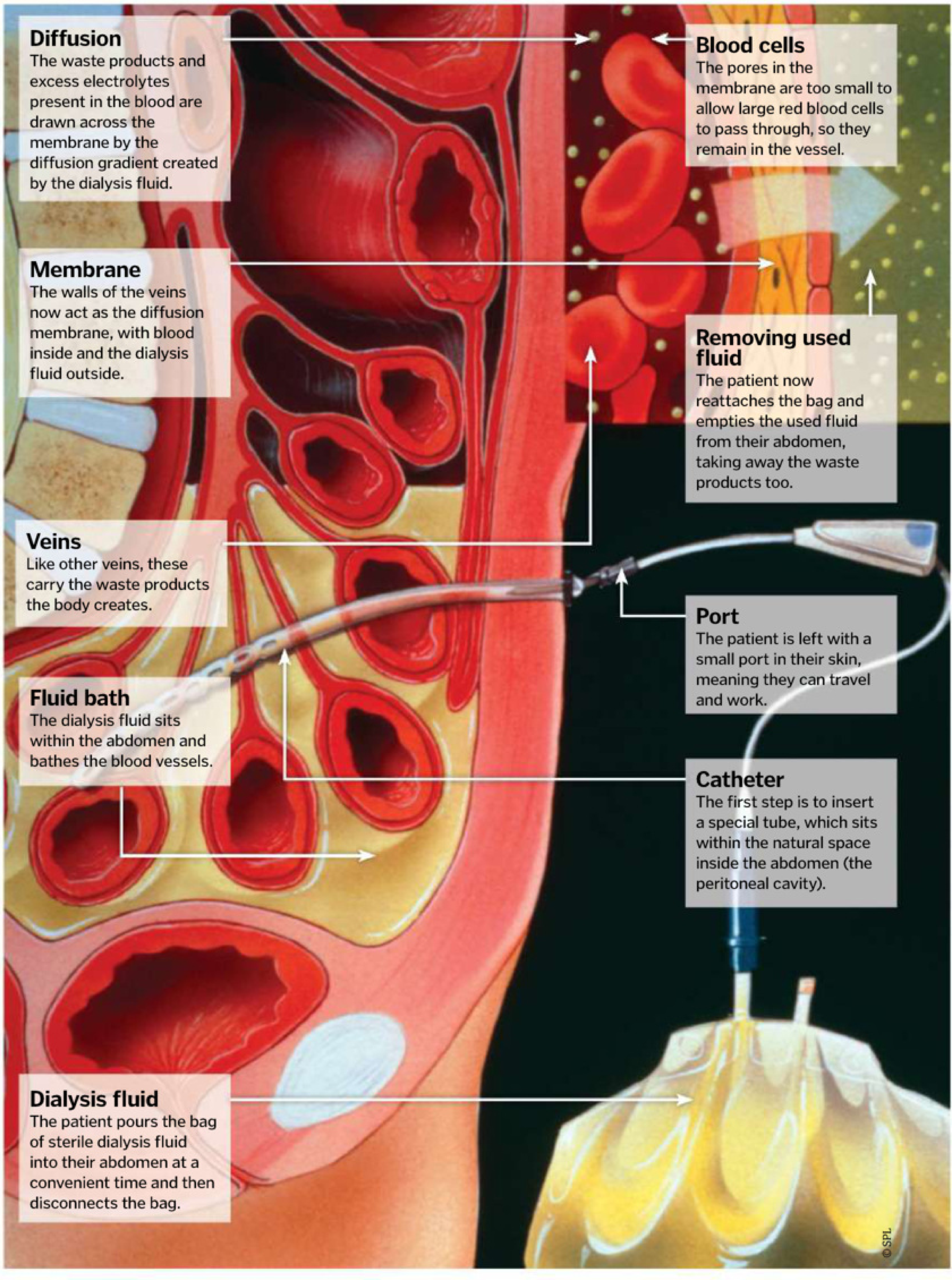
Dialysis machines date back to the Second World War. The technology developed rapidly as it was proven to save lives and today there are two main types: haemodialysis, which filters the blood, and peritoneal dialysis, which filters fluid within the abdomen. While life-saving, dialysis needs to be performed up to four times a week and is not without complications. A kidney transplant offers the best chance of long-term cure, but the number of patients on transplant waiting lists far exceeds the number of donated kidneys, so dialysis remains a key part of keeping people alive around the world.

How a dialysis machine works

Sterile tubing is attached to a vein (to take blood away from the body) and an artery (to return cleaned blood) in the patient's arm. The process relies on a semi-permeable membrane, a thin sheet with tiny holes that only allows molecules under a certain size to pass through. On one side of the membrane is the blood, carrying nutrients and waste products. On the other side is the kidney, containing early components of urine. The pores prevent large particles like red blood cells from escaping the bloodstream. This process is replicated exactly in the machine. On one side is the removed blood and on the other is a solution that draws out the waste products from the blood.

How peritoneal dialysis works

Learn how a different type of dialysis can fit into your working life



Human patient simulators

Using a combination of electronics, hydraulics and mathematical models, see how these mannequins can help us train for a real-life medical emergency

The simulation is managed by a sophisticated computer program, which integrates the incoming information from the sensors in the mannequin. Using complex mathematical models of real human physiology, the software alters the patient's condition in real-time as the medics attempt to treat the patient.

Blood vessels that are found in the arms, neck and groin pulse in time with the heart rate, which can also be monitored via electrical signals through the chest using an ECG machine. In the arm, a vein at the elbow allows a cannula to be inserted, and on-board fluids enable blood samples to be taken.

Pumps, hydraulics and motors, meanwhile, are used to control the patient's movements, by opening and closing the eyes, making the chest rise and fall, and even allowing for simulated convulsions.

The mannequin is packed with sensors in order to detect treatments as and when they are administered. If the procedure happens to be performed incorrectly, the simulation will react just as an actual patient would.

The most sophisticated simulators also allow drugs to be administered and are even able to respond based on the type and dosage, using a barcode system in order to alert the computer to the incoming medication.

Inside a patient simulator

These advanced medical training aids are packed with technology that replicates the complex functions of the human body

Consciousness
Light sensors in the eyes adjust the pupil size, altering reaction time depending on the condition of the simulated patient.

Chest sounds
Speakers in the chest allow medics to listen for irregularities in breathing or heartbeat.

Genitourinary
Catheterisation can be practised on the mannequin and on-board fluids even simulate urine flow.

Body fluids
Many of the most realistic models contain reservoirs, which produce replica body fluids such as blood, urine and saliva.

Airway
Realistic airways enable medics to practise intubation techniques. Some contain a gas analyser to identify the composition of inhaled air.

Cardiac arrest
Pressure sensors in the chest mean the mannequin responds to chest compressions.

Intravenous access
Veins in the arms allow intravenous drugs to be administered. The program is alerted by a barcode system.

Circulation
Mechanical components beneath the skin mimic the feel of pulsing arteries and electronics in the chest generate signals that can be picked up by an ECG machine.

Types of patient simulators

Adult
Adult simulators are used in medical and military training. By mimicking the circulatory system and airways, medics can practise emergency techniques so trainees can gain experience in managing life-threatening medical conditions without jeopardising real human patients.

Baby
Infant medical care is very different to that of an adult, and baby simulators provide specialised training in emergency infant care. The small mannequins allow intravenous injections to be performed and the membranes of the mouth turn blue if the mannequin is starved of oxygen.

Pregnant mother
These specialist mannequins are used to simulate childbirth and are capable of delivering a baby naturally, or by caesarean. Common medical complications – such as breech birth and postpartum haemorrhage – can all be re-created to enable medics to train for natal emergencies.

Virtual patients
Some patient simulators are entirely virtual, with no physical representation of the patient at all. These complex computer programs can model huge numbers of biological processes. They do not provide hands-on training, but instead allow scientists to rapidly test new medical hypotheses.

© CAE Healthcare

THE WORLD OF BIOMETRICS

How fingerprint scans and other technologies can identify you

In today's connected world, the need to verify our identity comes up countless times each day. Right now, we tend to do that by one of two means: with a physical token like a passport or a door key, or with a piece of knowledge like a password or PIN. But physical ID can be lost or counterfeited, and passwords can be stolen, hacked or simply forgotten.

Enter biometrics. Instead of relying on tokens or knowledge, biometrics uses distinctive measurable characteristics about a person to identify them. Because these are unique to individuals, they make more reliable identifiers, are tough to copy and are impossible to forget. Biometric identifiers are grouped into physiological characteristics, like fingerprints, iris patterns and vein geometry; and behavioural traits, like the way a person types, talks or walks.

Biometric identifications all begin with some form of scan or data collection. This information is then encoded. In the past, this step would be done manually, for example noting the locations of distinctive features in fingerprints, but nowadays computers convert these into numerical code. Finally, these mathematical descriptions get compared to a database in search of a match.

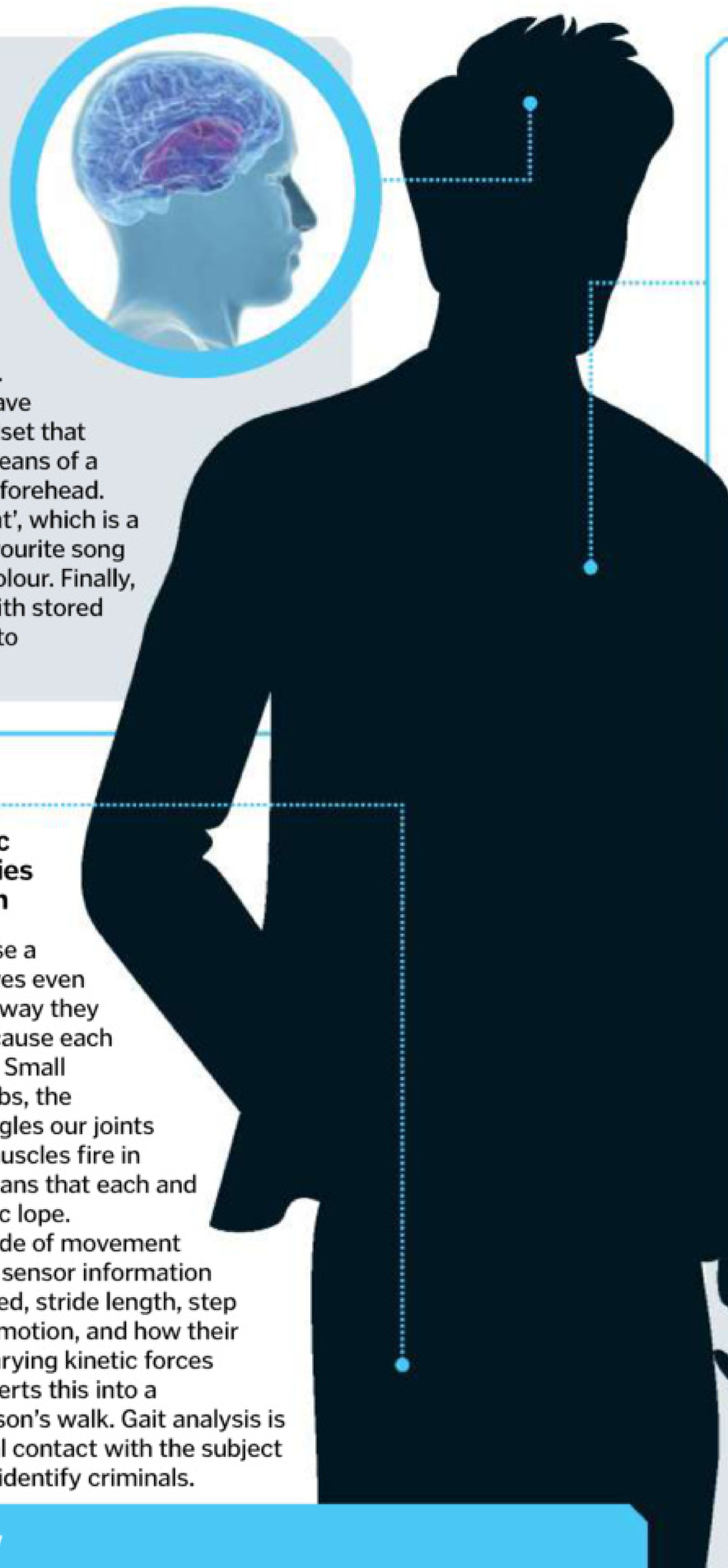
Biometrics can be used in a variety of settings; in national border control or high-security data, website and physical access. It can also monitor who is entering and leaving a workplace or to ensure hospital patients are correctly identified, as well as in law enforcement and security surveillance. Read on to learn about how your unique physical and behavioural characteristics can act as your new password for everything!

129 MILLION

FINGERPRINT ID SPEED RECORD

The number of fingerprints searched in less than one second by the world's fastest automatic identification system – DERMALOG Next Generation AFIS. At ten prints per person, that's more than the entire population of Portugal.

DID YOU KNOW? *Four in ten UK secondary schools now use biometric technology as a means of identifying pupils*



Brain waves

Great minds think alike, but signal differently

Even when two people think of the same thing, the electrical impulses in their brains differ slightly. Brain-wave biometrics exploits the fact that we all produce distinct patterns of alpha-beta brain waves.

To perform a biometric brain-wave authentication, a user dons a headset that measures their brain activity by means of a single dry-contact sensor on their forehead. Next, they think their 'pass-thought', which is a mental task such as recalling a favourite song or counting objects of a specific colour. Finally, their brain waves are compared with stored recordings of their pass-thoughts to authenticate their identity.

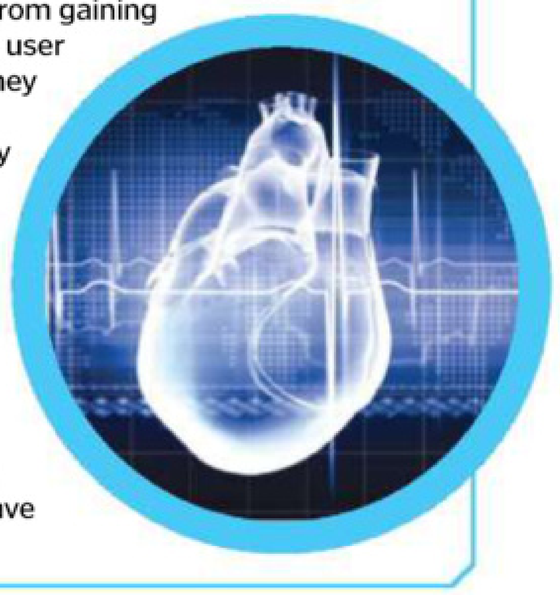
Heart rhythm

Forget your memory, all you need is a pulse!

The beat of your own drum – your heart rhythm – is unlike anyone else's. The heart's particular pattern is governed by factors including its shape, size and position in the body. This method could potentially rival a fingerprint for ID authentication purposes, according to the inventors of the Nymi rhythm band.

Cardiac rhythm is monitored using an electrocardiogram (ECG) and is graphically represented as a series of peaks and troughs that correspond to the electrical impulses generated by the heart as it beats. The Nymi wristband continuously compares the wearer's ECG waveform to that of the registered user of nearby devices. If the two match up, the band creates an encryption key, which it transmits to the devices via Bluetooth.

The Nymi makes it possible for devices to recognise their user and prevent imposters from gaining access to them. Wearing it, a user can unlock their devices as they come into close range, automatically sign out as they step away, perform secure transactions by verifying their ID at real-world checkouts, control devices with gestures, and even track their fitness levels. Thankfully, going for a run doesn't alter the characteristic shape of an ECG and age appears to have little effect.



Gait

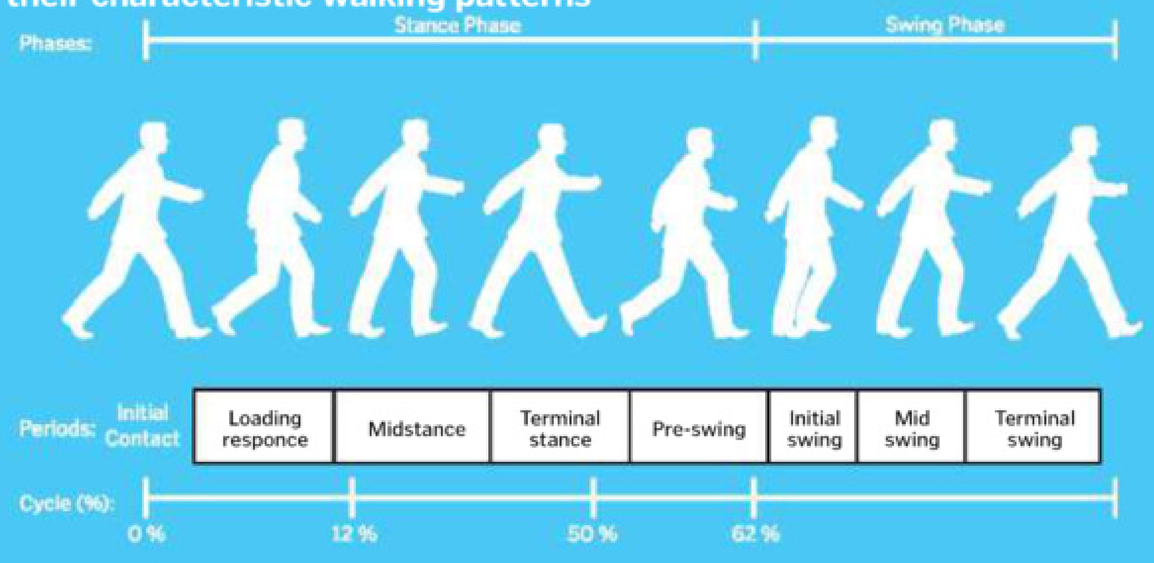
Although humans share basic movement patterns, gait varies widely from person to person

Ever noticed how you can recognise a friend approaching, before your eyes even focus on the details, just from the way they cut through the crowd? That's because each person's walk – or gait – is unique. Small variations in the lengths of our limbs, the dimensions of our muscles, the angles our joints make, and the complex way our muscles fire in sequence to propel us forward means that each and every one of us has a characteristic lope.

A gait analysis studies a multitude of movement parameters from video footage or sensor information – including a person's walking speed, stride length, step width, the angles of their joints in motion, and how their joints rotate and respond to the varying kinetic forces throughout their stride – and converts this into a mathematical description of a person's walk. Gait analysis is unobtrusive; it requires no physical contact with the subject and can even be done in secret to identify criminals.

Walk this way

Gait analysis identifies people based on their characteristic walking patterns



The stance and swing phases are when the lead foot is and isn't in contact with the ground, respectively. The timings of each phase are unique due to your musculoskeletal make-up.

Vein matching

No two people have identical veins – not even identical twins!

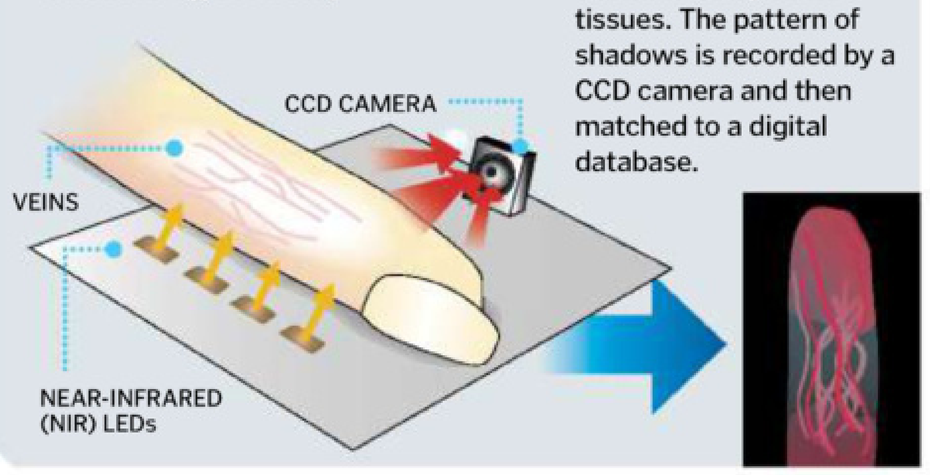
Just like fingerprints, everybody's vein geometry is completely unique and remains the same throughout their lives. Unlike fingerprints, however, vascular patterns are almost impossible to counterfeit because of the vessels' location beneath the skin's surface.

To map a person's veins, their hand or finger is placed into a scanner and illuminated with near-infrared light. A CCD digital camera takes a picture and, because haemoglobin in the blood absorbs the light but the surrounding tissues do not, the veins show up in the picture as black lines. Geometric details such as vein thickness, branching points and branching angles are extracted and mapped for comparison.

In a similar vein

Vein matching identifies a person by their unique vascular geometry

The light from a near-infrared light source penetrates the skin and is absorbed by veins but transmitted by other tissues. The pattern of shadows is recorded by a CCD camera and then matched to a digital database.



Facial recognition

This system identifies our unique facial topography

Humans are exceptionally skilled at recognising and distinguishing faces – there's even a special region of the brain devoted to the task – but computers are quickly catching up. Automatic facial recognition systems analyse the contours of faces to identify individuals from photos, video footage, or 3D surface maps.

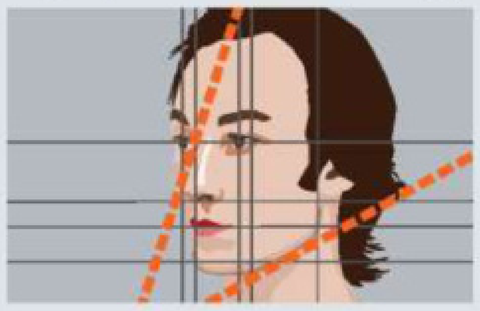
The technology creates a faceprint by measuring and mapping distinguishing features that aren't susceptible to alteration with expression and don't change with age. These include the curve of the eye sockets, the distances between the eyes, nose, mouth and jaw, the width of the nose and the shape of the cheekbones.

Because it can be done covertly and from a distance, facial recognition is useful for surveillance purposes, and 3D systems can even recognise faces in darkness, at angles of up to 90 degrees. The system isn't foolproof though: canny criminals can easily conceal their faces with masks.

A face in the crowd

How facial mapping and matching algorithms can identify you at a distance

Detection
Special software detects the presence of a face in a photograph or video footage.

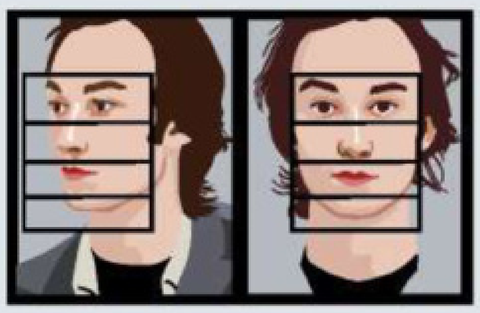


Alignment
The software deduces the alignment of the face with respect to the camera.

Measurement
The curves, ridges and valleys of the face are mapped at a resolution of less than 1mm (0.04in).

Representation
Facial feature measurements are digitised so the image can be compared with others in a database.

Compatibility conversion
To compare a 3D image with an older database of 2D images, an algorithm converts the source to 2D.

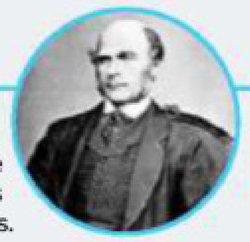


Matching
The encoded faceprint image is compared with those stored in a database, seeking a potential match.

KEY DATES
BIOMETRIC IDENTIFICATION

2000 BCE
Evidence suggests fingerprints were used on clay tablets in transactions in Ancient Babylon.

1870s
Alphonse Bertillon's anthropometrics catalogue and identify serial criminals by their body measurements.

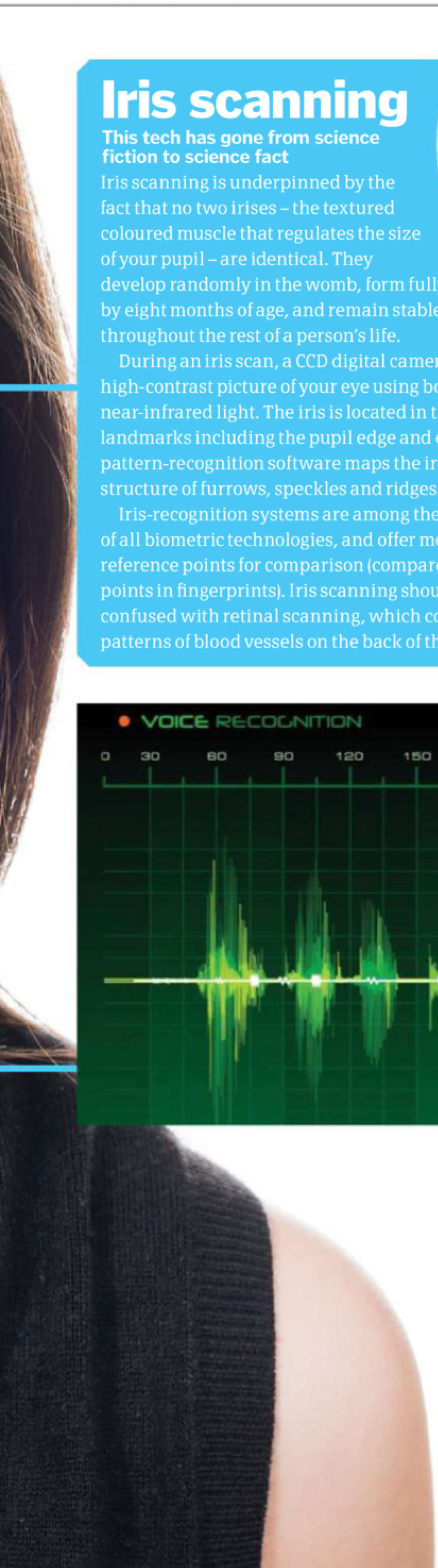


1892
Sir Francis Galton develops a fingerprint classification system using prints from all ten fingers.

1994
The world's first successful iris-recognition algorithm is patented by Dr John Daugman.

2013
India's Aadhaar project finishes capturing biometric data of over half a billion residents, making it the world's largest biometric database.

DID YOU KNOW? *The Canadian Kennel Club has been accepting dog-nose prints as proof of identity since 1938*



Iris scanning

This tech has gone from science fiction to science fact

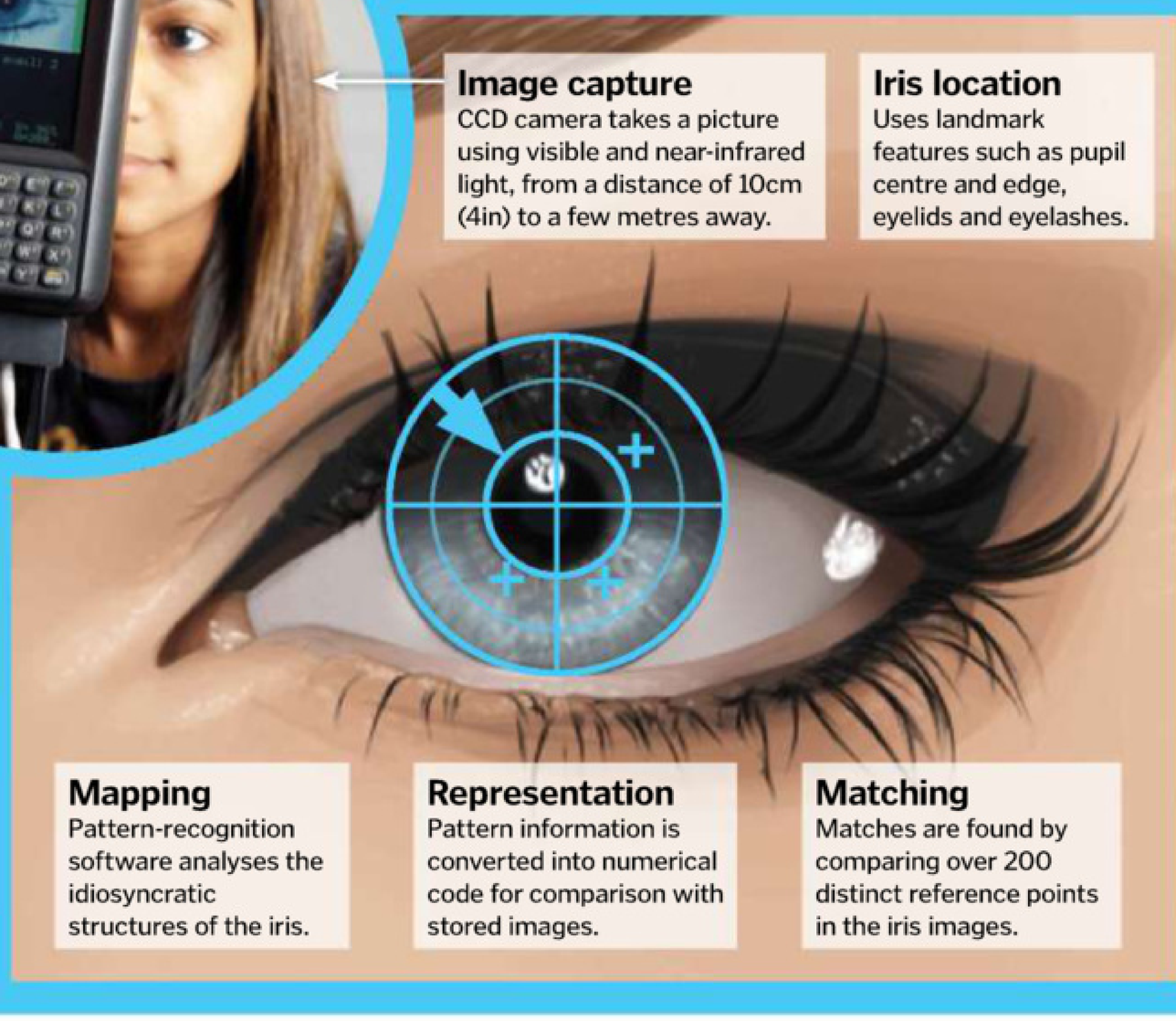
Iris scanning is underpinned by the fact that no two irises – the textured coloured muscle that regulates the size of your pupil – are identical. They develop randomly in the womb, form fully by eight months of age, and remain stable throughout the rest of a person's life.

During an iris scan, a CCD digital camera takes a high-contrast picture of your eye using both visible and near-infrared light. The iris is located in the image via landmarks including the pupil edge and eyelids, and pattern-recognition software maps the iris's distinct structure of furrows, speckles and ridges.

Iris-recognition systems are among the most accurate of all biometric technologies, and offer more than 200 reference points for comparison (compared to 60 to 70 points in fingerprints). Iris scanning should not be confused with retinal scanning, which compares the patterns of blood vessels on the back of the eye.

Image capture
CCD camera takes a picture using visible and near-infrared light, from a distance of 10cm (4in) to a few metres away.

Iris location
Uses landmark features such as pupil centre and edge, eyelids and eyelashes.



Mapping
Pattern-recognition software analyses the idiosyncratic structures of the iris.

Representation
Pattern information is converted into numerical code for comparison with stored images.

Matching
Matches are found by comparing over 200 distinct reference points in the iris images.

Voice recognition

You – and your dulcet tones – are a truly singular voice

The sound of your voice is governed by physiological factors – the shape of your vocal tract, airways and surrounding soft-tissue cavities – as well as behavioural factors, linked to personality and peer influence, which affect the motion of your mouth as you speak. Together, these mean that everyone's voice is distinct.

Voice-recognition systems record a spectrogram of how sound frequency varies with time. Qualities like the acoustic characteristics and intensity dynamics of the speaker's voice are extracted and used to identify them.

Simple voice-authentication systems require a person to speak a previously recorded password, but these can be vulnerable if a hacker has a recording of a person saying their password. More advanced systems prompt a user to say a random word and authenticate this against a complete profile of the person's voice.

Fingerprinting

How smartphone and airport fingerprint scanners work

Fingerprint identification is the oldest and most widely used biometric method. Our fingerprints – the pattern of loops, whorls and arches – form randomly in the womb and remain unchanged throughout our lives. Like snowflakes, there are infinite pattern possibilities and scientists believe no two fingerprints are ever formed the same way.

Although there is evidence that fingerprints were used as a person's mark or signature in Ancient Babylon, they have been systematically used to identify people since 1892, when Sir Francis Galton developed a way to classify ten-finger print sets. Galton identified common local features in fingerprints – like where the ridges start, end and split along their paths – which became known as 'Galton Points.'

Galton's legacy lives on in today's fingerprint matching, which uses the location and orientation of a subset of his points, called minutiae. With the advent of computing technology in the 1960s, fingerprint matching became automated. Today, the FBI's IAFIS (Integrated Automated Fingerprint Identification System) – holds over 100 million individuals' prints and performs over 60 million searches on the database per year.

Prints are collected by a variety of means. They can be lifted from a crime scene using fine powder or reactive chemicals, or they can be taken from a person by inking their fingers and stamping them on paper. More recently, they can be captured digitally with a variety of sensors, including optical, thermal and capacitance sensors. Sophisticated computer algorithms analyse the minutiae patterns in the prints and look for matches in a database.

Out of print

Fingerprint analysis is the oldest and most established method of biometric identification

Mapping
Characteristic minutiae – the location and direction of ridge ends, swirls and splits – are sought out and mapped.

Capture
Subject places their fingers on scanning surface and the system records the skin's pattern of ridges.

Pattern extraction
Geometric patterns between different minutiae are plotted.

Representation
Relational patterns are converted into numerical code so they can be compared with stored data.

Matching
System finds potential matches between the encoded prints and the database by comparing over 60 individual reference points.

Are fingerprints really unique?

Fingerprint evidence has been a staple of forensic investigations for over a century and is considered to be conclusive proof of a suspect having been at a crime scene. But some experts contend the underlying principle that no two fingerprints are alike. The predominant patterns in your prints – whorls, loops or arches – run strongly in families and, while evidence suggests it is improbable, proving that no two people have identical prints is practically impossible.

Even if they truly are unique, the collection and identification process can be prone to human error. Crime scene fingerprints can be partial, smudged or degraded, and the exact print left by an individual finger can vary slightly from one impression to the next. Also, humans aren't alone in having fingerprints. Chimps, orangutans and koalas all share the trait and their prints could easily be mistaken for human ones at an interspecies crime scene.

Studies show that even experts are prone to mistakes, coming to different conclusions than their peers and even identifying the same set of prints differently on second glance. This, at least, is one weakness that automated fingerprint identification by computers can banish, reducing the risk of false convictions and unjust punishment.

Keystroke recognition

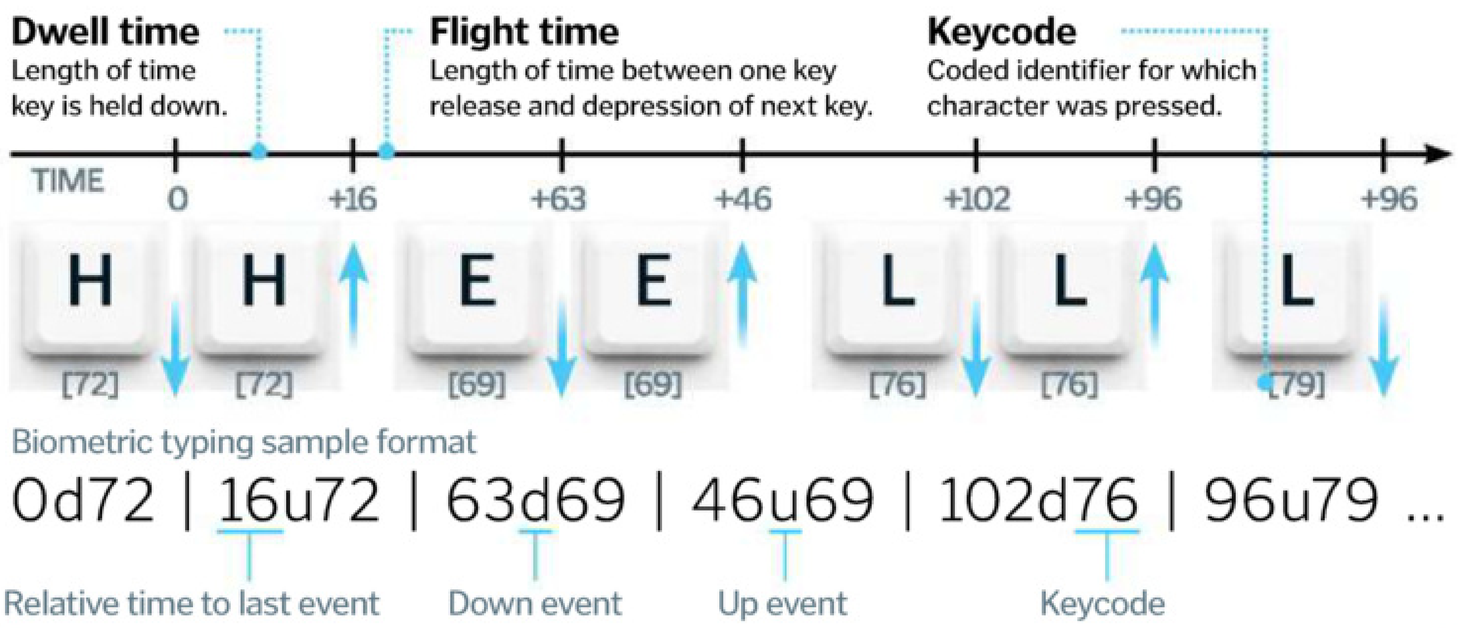
Your typing rhythm is as distinctive as your handwriting or signature

Typing rhythms are idiosyncratic because each of us has particular characters that always seem to evade us and certain common letter combinations that fly from our fingers faster than the rest. Keystroke recognition analyses the rhythm and features of a person's typing style by logging nuances like how long they take to reach and depress a key (flight time) and how long they hold keys down (dwell time).

Keystroke-timing data can be collected from any keyboard and compared with stored pattern data to confirm the user is who they claim to be. But the technique is limited by the fact that, even though an individual's typing rhythm is independent of how fast or slow they type, other factors such as how tired they are or whether they have consumed alcohol can interfere with it.

A certain type

Keystroke recognition uses your typing rhythms to authenticate your identity



Biometric passports

Biometric documents make identity fraud near impossible

A passport is the ultimate proof of identity. Aside from your birth certificate, it is pretty much the last document you would ever want to be stolen or forged; a thief could wreak all sorts of havoc while assuming your identity, leaving you to deal with the consequences. National border-security agencies need to monitor exactly who enters and leaves their country, a need that, in these times of mass global travel and international terror threats, has become ever-more pressing.

A biometric passport, or e-passport, combines the paper passport of old with a tiny chip and an antenna that allows it to be read electronically. The chip is embedded into a page of the passport in such a way that it can't be tampered with. The chip contains the same basic data as the standard passport information page, plus encrypted digital images of one or more of the holder's biometrics.

When the holder steps up to the immigration window, the relevant biometrics are captured and then compared to those in the passport. All passports now issued in the UK are biometric, and contain information about the holder's face, such as the distances between the eyes, ears, nose and mouth.

Biometric revolution

Dr Arun Ross, associate professor of Computer Science and Engineering at Michigan State University, answers our questions on the amazing burgeoning field of biometrics

What major advances have been made in biometrics in the last decade?
Arun Ross: First, the matching accuracy of biometric systems has substantially improved. Second, it's now possible to search through large databases of identities very quickly, due to improvements in computational power and development of efficient indexing models. Third, a number of new sensors have been designed. For example, it's now possible to perform iris recognition at a distance.

What kind of matching accuracies are we talking about?
Ross: That depends on the kind of data you're working on. If you work with mugshots or high-quality fingerprint images, recognition rates can exceed 99 per cent. But if you're dealing with low-quality data from surveillance video, or degraded fingerprints that are lifted from a crime scene, the performance can drop to the 60s.

Where are biometric identification techniques having the most impact?
Ross: Early systems were mostly used by law enforcement for criminal investigations, but now we're seeing biometrics being incorporated into border security systems and national ID card programs. We're also seeing biometrics enter the consumer electronics market, including smartphones. This is likely to become commonplace as we conduct more and more sensitive transactions online, so the need to verify our identities becomes especially important.

What are some of the ethical or security concerns surrounding biometric data collection and storage?
Ross: One concern is whether data will be used for purposes outside those expressed at the time of collection – a phenomenon we refer to as function creep. There are also concerns over data theft and misuse. For example, can someone steal my fingerprint as it is being transmitted through cyberspace and play it back for another transaction, or create a fake fingerprint using the stolen data? Legal scholars and biometric researchers are working to see how these security and privacy concerns can be mitigated.

What developments on the horizon strike you as most exciting?
Ross: Many of us store, access and transmit extremely sensitive information – both personal and professional – using our smartphones, so incorporating biometric solutions into our phones will become important for applications such as online banking. In several countries in Africa, smartphone use is rapidly increasing as access to the internet becomes ubiquitous. Biometrics could be used to great effect there to, for example, verify identities remotely when people use their smartphones to access resources like microloans.

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Robotic surgery

Medical technology in the operating theatre has come on leaps and bounds, but it still needs a helping hand from humans...

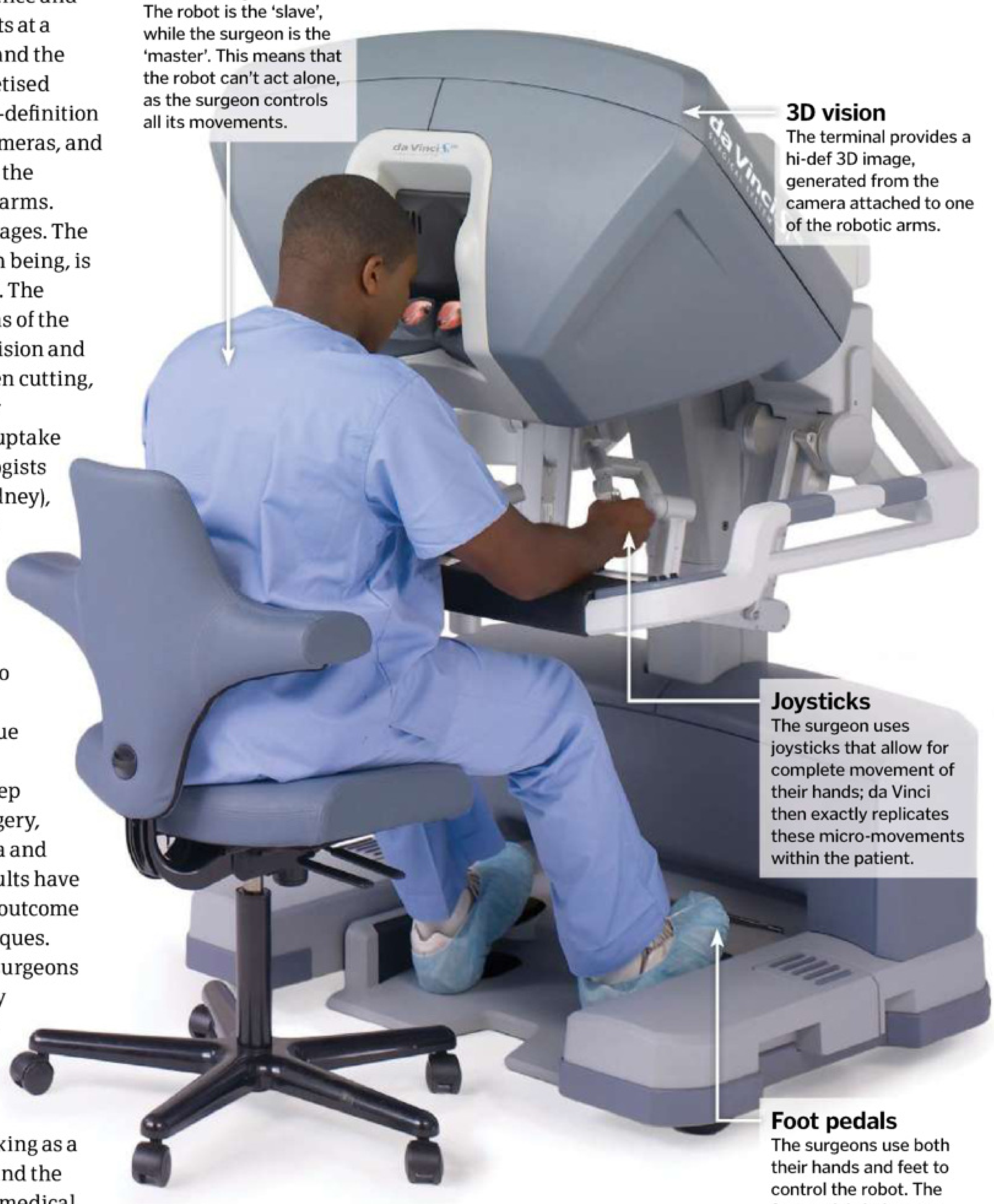
Robotic surgery allows for control and precision previously unknown to surgeons. Contrary to popular belief, the robot does not operate on the patient alone. It is a 'slave' to a human 'master', meaning it is not a true robot (these have intelligence and react automatically). The surgeon sits at a console next to the operating table and the robot is placed around the anaesthetised patient. The surgeon looks at a high-definition 3D image provided by the robot's cameras, and special joysticks are used to control the ultra-fine movements of the robotic arms.

This brings many exciting advantages. The camera, previously held by a human being, is now held perfectly still by the robot. The movements and angles that the arms of the machine provide allow for fine precision and less damage to adjacent tissues when cutting, leading to reduced pain and a faster recovery. This has led to very rapid uptake by some specialists, including urologists (who operate on the bladder and kidney), gynaecologists (who operate on the uterus and ovaries) and heart surgeons. As with most technologies, there are downsides to using robots in operations. They are expensive, large, cumbersome to move into place, and remove the important tactile feeling of real tissue between the surgeon's fingers.

Robotic surgery is considered a step forward from standard keyhole surgery, where the surgeon holds the camera and operating arms. However, early results have shown that there are practically no outcome differences between the two techniques. Combined with higher costs, some surgeons think this means robots are actually inferior to current techniques. This has led to the development of on-going trials, comparing robotic to standard keyhole surgery. Surgeons around the world are working as a single, giant team to deliver these, and the results will determine the future of medical robots for generations to come.

da Vinci in action

This state-of-the-art surgical system works as part of a big team to deliver high-precision surgery. Find out what role it plays now...



DID YOU KNOW? *Surgical robots are incredibly expensive, with current versions costing around £900,000 ($1.45mn) each*

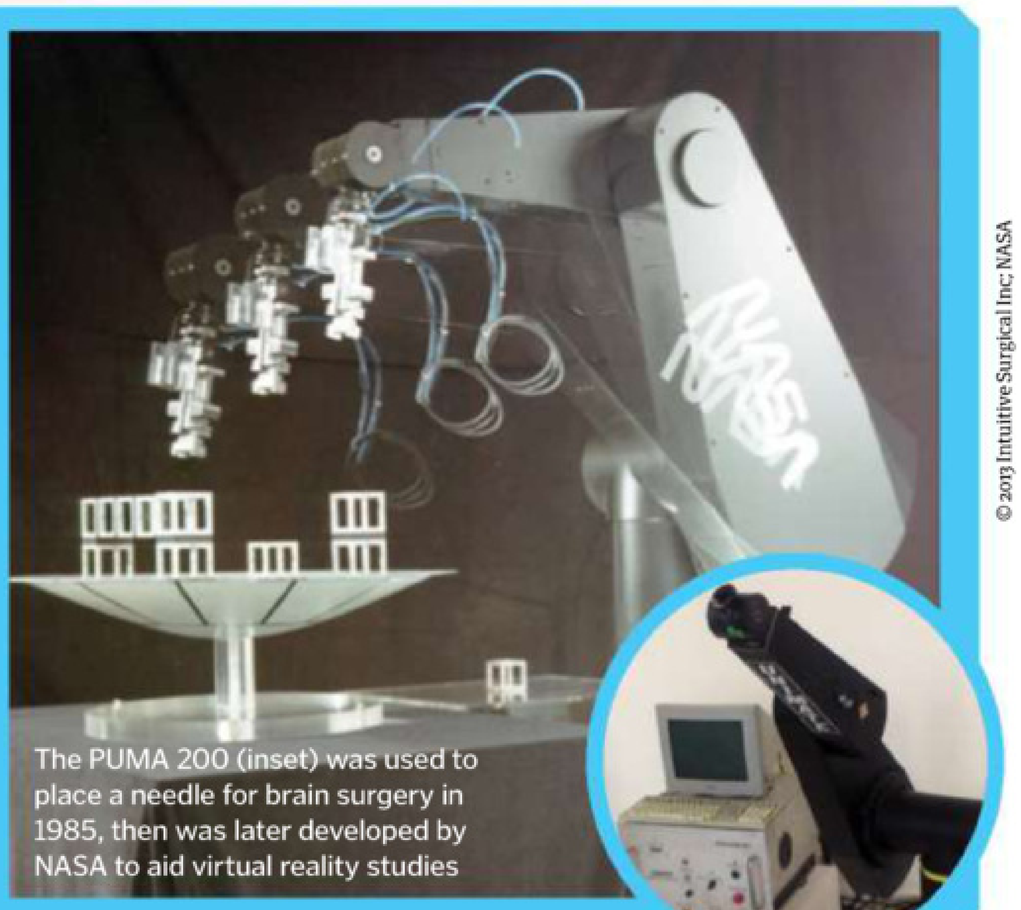
Robotic arms
The ends of the robot's arms, which include a camera and operating instruments, are placed in the operating site at the start of the procedure.

Internal view
The camera is projected onto several screens around the operating theatre, so the team knows exactly what the surgeon is doing.

Surgical team
Someone always remains 'scrubbed up', so that they are sterile and ready to move any parts of the patient or robot.

Fluorescence imaging
Fluorescence imaging is still in the experimental stages, and is right at the cutting edge of technological science. Indocyanine green (ICG) is a dye that was initially developed for photography and is now used clinically. It is injected into the patient's bloodstream, and has been adapted so that it sticks to cancer cells – for example, within the bowels. At the time of surgery, the doctor inserts a camera into the patient's body (either using their hands or a robot), and the dye is excited by light at a precisely matching wavelength. This creates bright green fluorescence, distinguishing cancerous from normal tissue and allowing the surgeon to make precise incisions.

The evolution of robotic surgery
The current robots in use, like the da Vinci Surgical System, are second generation. The first generation, like the Unimation PUMA developed in the Eighties, had very limited movements and could only carry out specific tasks. The second generation brought a range of fine and varied actions, which surgeons rapidly adapted to. These new-and-improved robots were pioneered and driven forward by North American health systems. Uptake has been slower in Britain due to health budgets, at a time when other treatments have an even bigger impact on patient outcome. There is excitement over development of the third generation of robot, which promises to be more compact, faster and to be packing in even more cutting-edge technology. The future may see telesurgery, where the surgeon in one place (eg a hospital) performs robotic surgery on a patient elsewhere (eg an injured soldier on a battlefield).



The PUMA 200 (inset) was used to place a needle for brain surgery in 1985, then was later developed by NASA to aid virtual reality studies

© 2013 Intuitive Surgical Inc; NASA

A cornea-reshaping lens

Sleeping with this special contact lens can correct near-sightedness

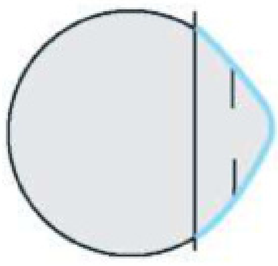
Sick of spectacles? Can't handle contact lenses? There's now a way to correct your vision; orthokeratology. This method involves a type of gas-permeable contact lens that reshapes your cornea while you sleep. When you wake up, you remove the lenses and your vision is 20/20 for the day. This will last for a few days until your eyes' corneas return to their natural shape, but you can repeat the process.

The procedure, which is also known as corneal refractive therapy, is most effective for people with mild myopia (near-sightedness), hyperopia (far-sightedness) and astigmatism. 'Ortho-K' can also help correct or prevent the onset of presbyopia, where the eye's ability to focus on close objects is diminished. As well as being a day-to-day treatment, it can be used to slow the onset of near-sightedness in children.

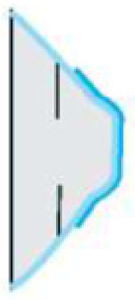
Orthokeratology is primarily designed for people who do not qualify for laser eye surgery. The reshaping of the cornea is only temporary, so there is very little risk for the eye. The surface of the eye is measured by a corneal topographer, which maps the cornea so the corrective lens can be moulded in the right shape. In some patients 20/20 vision isn't possible, but 20/40 – usually the legal limit for diving – is the aim point for the majority of procedures.

Corneal refractive therapy

What happens to your eye overnight

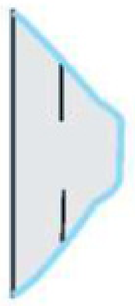


Diagnosis
Your near or far-sightedness may be due to your cornea being the wrong shape. This is where orthokeratology comes in.



Correction
The cornea in each eye will adjust into a new mould overnight to give you better eyesight. It is a completely painless process.

Fitting the lens
The lens is put onto your eye just like a standard contact lens. You wear it as you snooze and take it out the following morning.



The next day
The following morning your sight will have improved. Lasting for a few days, the process can be repeated for extended effect.

How to 3D print an organ

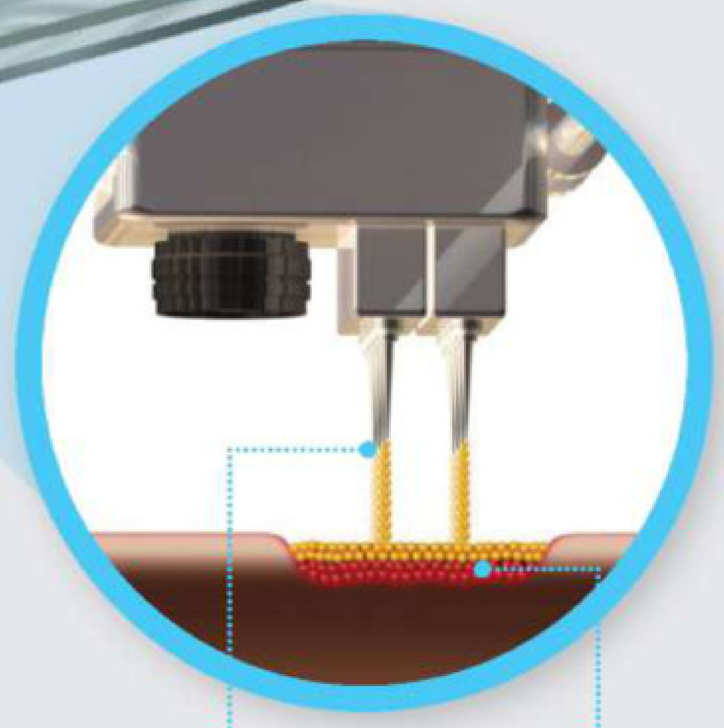
The stages of printing a replacement organ with this revolutionary technology

Scan
The patient has a CT or MRI scan to build up an image of the organ.

Model
A computer model is created from the scan.

Acceptance
Doctors then wait to see if the organ is accepted by the body.

Implant
The organ is placed into the body where it is connected up to the relevant systems.



Printing
The organ is printed using human cells and a sticky gel that binds it together.

Gel removal
The gel gets washed away, leaving just the cells in the shape of the organ.

3D-printed organs

The next step in the world of 3D printing

At the turn of the century, printing was limited to words and pictures on a page. Now, in less than two decades, we are on the cusp of being able to print human organs. Patients are sent for a CT or MRI scan that maps out the organ that needs to be printed. A digital model is then created in a computer. The printer uses human cells mixed with a gel to build up a 3D image of the organ. The gel is then removed, leaving just the cells. This would then be implanted into the patient. There are still many challenges to overcome in 3D printing organs, such as creating arteries, veins and capillaries, but the day we can replace a person's liver, kidney or even heart with a 3D-printed organ seems to be creeping ever closer.

© SPL; Thinkstock

Taking photos in the body

How do we capture images from inside the human digestive system?

An endoscopy is any operation involving the study of the inner workings of the human body. Traditionally, an instrument called an endoscope is used, but more recently tiny cameras inside capsules we can swallow have been taking their place. Specialising in the inspection of the intestines, oesophagus and stomach, it can examine places the endoscope could never reach. In particular, it studies the three major sections of the small intestine: the duodenum, jejunum and ileum.

About the size of a pound coin, the capsule transmits images to outside data recorders. It moves naturally through the digestive tract and is designed to help diagnose the causes of chronic diarrhoea, inflammatory bowel disease, abdominal pain and malabsorption.

To capture images, the mechanism shines a light from its LED source onto the wall of any part of the gastrointestinal tract. These images are then transported by radio waves to a nearby receiver or monitor for analysis.

If there's a downside, it is that currently the camera can't be stopped to take a closer look at anything, as it's moved by natural peristalsis.

To date, over 400,000 procedures have been performed worldwide and retention has occurred in only 0.75 per cent of cases, so the chances of it not passing through safely are very slim. In around eight hours the capsule can capture an incredible 50,000 or so images.

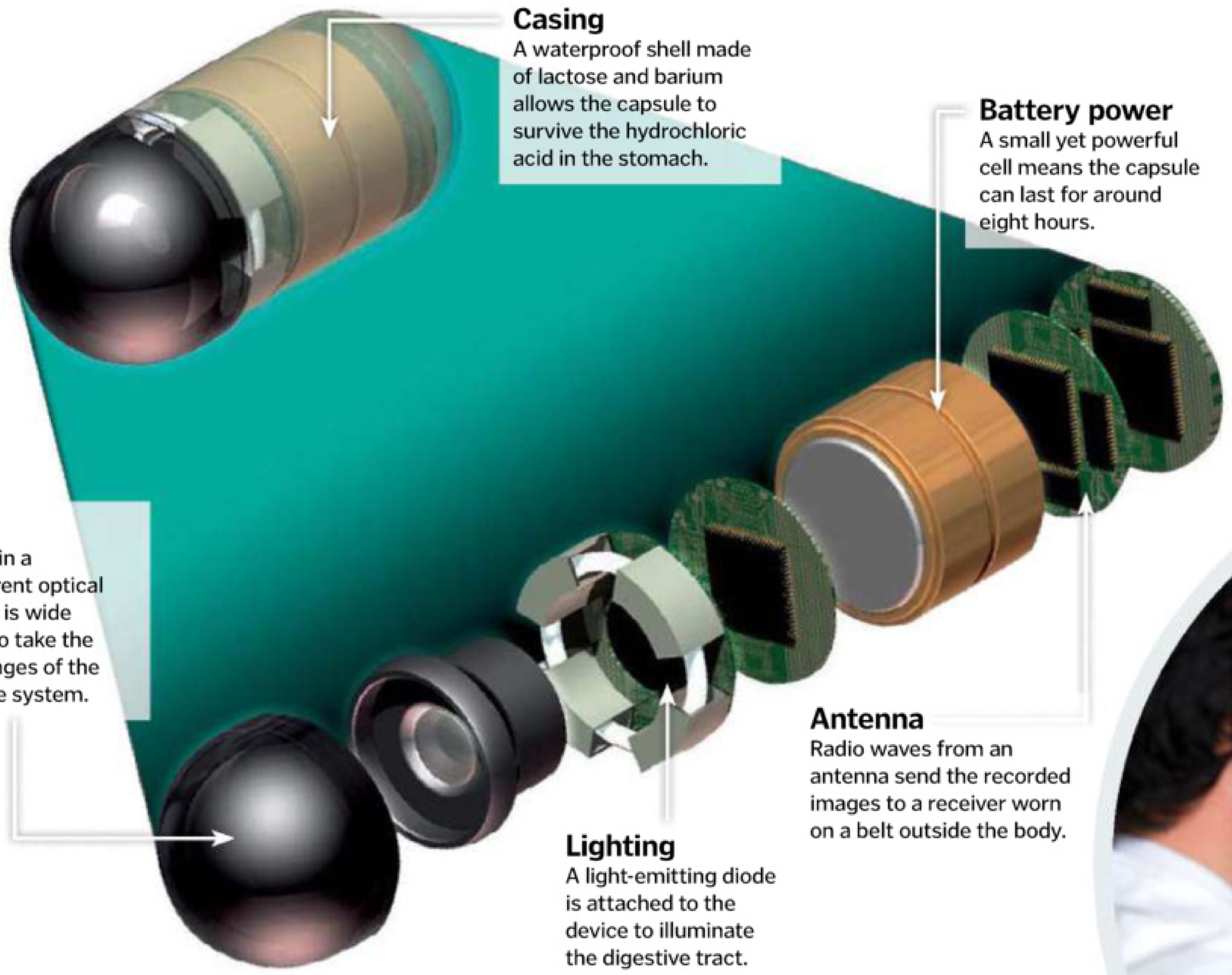
It costs about £600 ($1,000) to administer but its ability to explore parts of the digestive system in unprecedented detail – outside invasive surgery – is invaluable.

Nil by mouth

Camera capsule endoscopy is a painless and relatively fast process. To allow the procedure to work effectively, the patient must observe a few important measures. Prior to examination, the patient must not eat or drink anything for 12 hours. In some cases, patients may also need to cleanse their bowel before the procedure takes place. After taking the capsule, you can move around as long as you don't make any sudden movements. The vast majority who have used the capsule said they felt no pain or discomfort. You can drink clear liquids two hours after ingestion and eat food after about four hours.

The camera in a pill

What technology makes up this inner-body explorer?



Casing
A waterproof shell made of lactose and barium allows the capsule to survive the hydrochloric acid in the stomach.

Battery power
A small yet powerful cell means the capsule can last for around eight hours.

Lens
Housed in a transparent optical dome, it is wide angled to take the best images of the digestive system.

Lighting
A light-emitting diode is attached to the device to illuminate the digestive tract.

Antenna
Radio waves from an antenna send the recorded images to a receiver worn on a belt outside the body.

Images can be instantly transmitted to a computer for closer analysis

© Rex Features; Corbis; DK Images

EXO SUITS

THE FUSION OF MAN AND MACHINE WAS THOUGHT THE STUFF OF SCIENCE FICTION, UNTIL NOW

Iron Man is no longer the sole domain of comic books and film superheroics. Thanks to advanced robotics and human-machine interfaces, mechanised exoskeletons are being adopted worldwide. From machines capable of turning men into super-soldiers to cyborg implants clever enough to make the disabled mobile, the concept of human augmentation is rapidly transitioning from pipe dream to power on, with a host of companies and developers producing systems to make humans quicker, stronger and more perceptive.

Why is this revolution happening now? It's a combination of advanced discussion regarding the ethics of such augmentations by the Earth's brightest minds and a ravenous, insatiable drive by science and technology corporations to take humanity into a glorious new age. Before, scientific developments such as these would have been stamped out by fanatics, now if a person is born without the use of their legs they will still be able to walk and live their life like they never thought possible.

Strap yourself in and power up your mind as **How It Works** takes you on a tour through some of the most groundbreaking advancements changing the world in the fields of robotics and bionics. Welcome to the human-machine fusion revolution.

1,000ft

DEEP DIVING SUIT

A 240kg (530lb) deep-sea diving suit called the Exosuit, a next-generation Atmospheric Diving System (ADS), has enabled scientists to explore the ocean as far as 305m (1,000ft).

DID YOU KNOW? *The first prototype for the Hybrid Assistive Limb (HAL) was built in 1997*

HAL

HUMAN LIMBS EVOLVED

One of the most useful developments in human augmentation right now is Cyberdyne Inc's Hybrid Assistive Limb, codenamed HAL. HAL is the world's first cyborg-type robotic system for supporting and enhancing a person's legs, giving them the ability to walk if disabled.

Attached to the user's lower back and legs, HAL works in a five-step process. The user merely thinks about the motions they want to undertake, such as walking. This causes the user's brain to transmit nerve signals to the muscles necessary for the motion to take place. At this stage, a disabled user wouldn't be able to receive these nerve signals correctly in their limb muscles, but with HAL attached, they can. HAL is able to read the user's emitted bio-electric signals (BES), faint subsidiary signals from the brain-muscle signals that extend to the surface of the user's skin. By detecting these signals, HAL is then able to interpret the motion intended by the user and execute it, allowing them to move.

What is most exciting about HAL is its potential to train disabled individuals to move without its help. That is because every time HAL helps its user move, a natural feedback mechanism sees the user's brain confirm the executed movement, training the user's body to transmit those nerve signals correctly. While still some way off, continued development could eventually see HAL train a disabled person to walk unassisted.

Top 5 movie mechs

Gipsy Danger

Pacific Rim (2013)

One of the most important mechs from 2013's *Pacific Rim*, Gipsy Danger helps humanity combat inter-dimensional beasts bent on Earth's destruction.

Power Loader

Aliens (1986)

Piloted by Ripley in James Cameron's *Aliens*, the Power Loader mech helps Sigourney Weaver's feisty protagonist face off against the fearsome alien queen.

AMP

Avatar (2009)

Another hot mech from the mind of James Cameron, *Avatar*'s AMP plays a key role in the film's finale, with the baddie wreaking a whole lot of havoc in one.

Rhino

The Amazing Spider-Man 2 (2014)

Russian mobster Aleksei Sytsevich breaks out of prison and tears up Manhattan in a mech suit inspired by a rhinoceros.

APU

The Matrix Revolutions (2003)

Protecting the remnants of humanity against the sentinels of the *Matrix* universe, the APU deals huge damage with big guns.

No longer the sole domain of comics and movies like *GI Joe*, exoskeletons are helping soldiers in the field

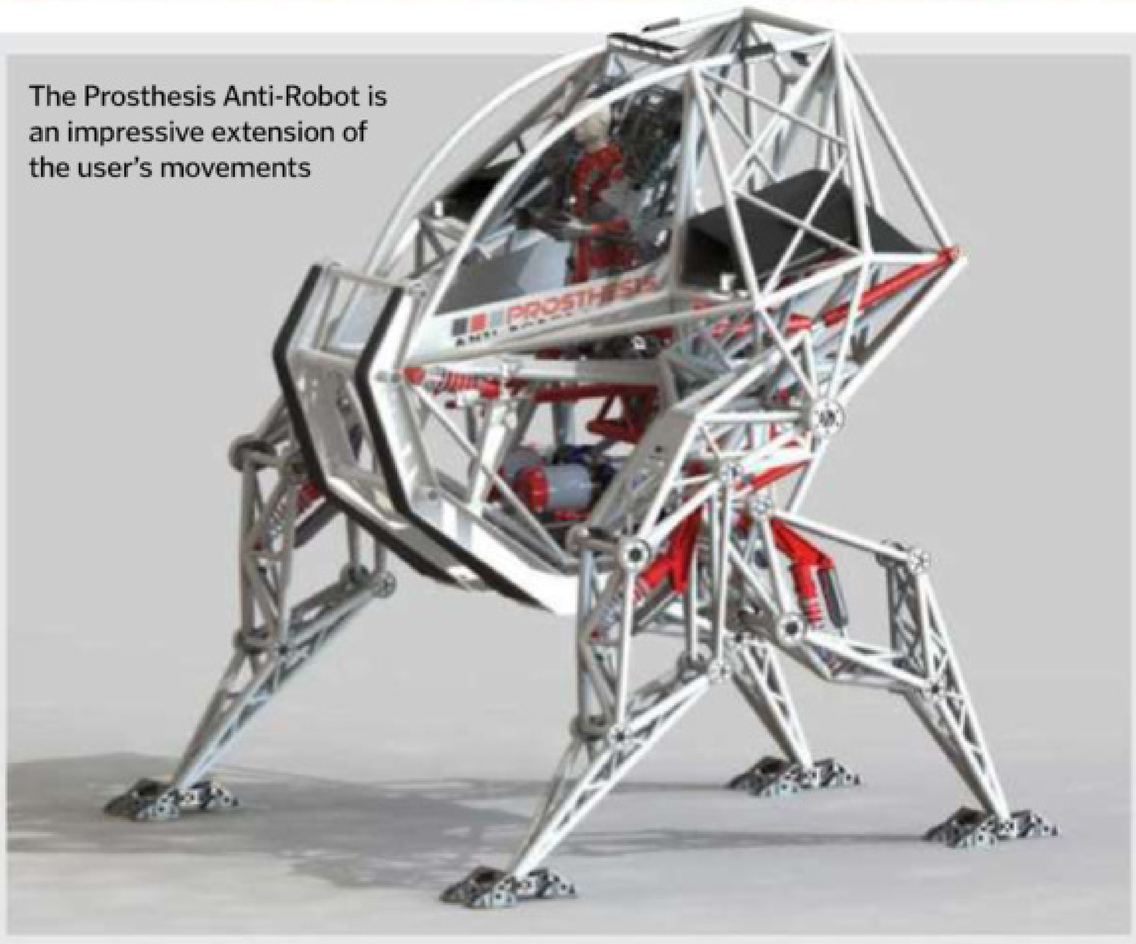
HULC

FASTER, STRONGER, TOUGHER

While Cyberdyne Inc's HAL is helping disabled people move once again, Lockheed Martin's HULC Exoskeleton is transforming able-bodied soldiers into mechanised warriors capable of feats of strength, speed and endurance never before seen by humans.

A hydraulic exoskeleton, the HULC allows soldiers to perform superhuman feats such as carrying loads of 90 kilograms (200 pounds) over difficult terrain for hours on end, all the while retaining maximum mobility. It achieves this by augmenting the soldier with a pair of powered titanium legs and a computer-controlled exoskeleton with a built-in power supply. This mechanism transfers the weight carried by the soldier into the ground, while providing power for continued, agile movement in the theatre of war.

Due to the HULC's advanced composite construction and build materials, it also acts as armour for its user, protecting them from musculoskeletal injuries caused by stress from carrying heavy loads. Indeed, when you consider that HULC may also improve metabolic efficiency in its user, reduce oxygen consumption and improve the rate of muscle wear, its hard not to see the future of frontline combat becoming reliant on these mech warriors.



The Prosthesis Anti-Robot is an impressive extension of the user's movements

RACING BOT

THE ULTIMATE PROSTHESIS

The Prosthesis Anti-Robot is a towering machine operated purely by human body movements. If that doesn't impress you, how do you feel knowing the Anti-Robot weighs over 3,400 kilograms (7,500 pounds) and is 4.6 metres (15 feet) tall?

The pilot can move such a huge machine by their own efforts thanks to an interface that attaches to their arms and legs and translates the movements of their limbs into the robot's four hydraulic legs. This, along with positional and force feedback, means the pilot's limbs directly correlate to those of the machine and when the force on them increases, the limbs get harder to move. A suspension system also helps the pilot feel when the bot's feet connect with the ground.

The Anti-Robot clearly highlights the possibilities of exoskeletons, with human strength and speed not only dramatically increased but also transferred into a machine many times their size. It's not hard to foresee construction workers suited up and shifting huge crates with ease in the near future.

The rise of the mechs

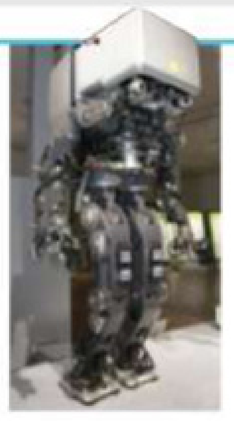
A timeline of real-life robotic tech

1961
Jered Industries in Detroit creates the Beetle, a tracked mech tank weighing 77 tons. The pilot is shielded by steel plating.

1968
General Electric creates the first cybernetic walking machine, a piloted mech with hydraulic hands and feet.

1989
MIT creates Ghengis, a small robot insect capable of scrambling over rough terrain while remaining stable.

1993
Honda unveils its first humanoid robot, the P1, which can walk around on two feet while tethered. It evolves into the now-famous ASIMO.



2000
DARPA, the US Defense Advanced Research Projects Agency, requests proposals for a powered military exoskeleton. It chooses the Sarcos XOS.

THE STATS
PROSTHESIS ANTI-ROBOT

HEIGHT **5m** | WIDTH **4.9m** | LENGTH **3.3m** | MASS **3,400kg** | STRIDE LENGTH **4.5m** | MAX SPEED **30km/h**

DID YOU KNOW? *The Prosthesis Anti-Robot project is a 100 per cent volunteer-staffed project*

BIONIC WALKER

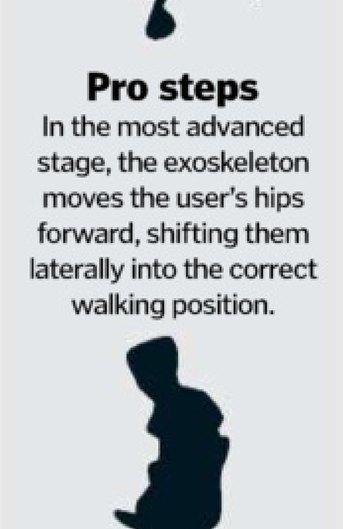
SUIT UP!

The most advanced gait-training exoskeleton currently in use, the Ekso Bionic Suit has been specially designed to grant people with paralysis a means of standing and walking. Once wearing the Bionic Suit, those who have suffered from neurological conditions such as strokes, spinal cord damage or traumatic brain injury can re-learn correct step patterns and weight shifts – things that able-bodied humans take for granted – all the while supported by a system that assists when needed and records every movement for later analysis.

The Bionic Suit already has an shining record, with every medically cleared user walking in the suit in their first training session. Fitting the suit takes just five minutes so doctors can treat multiple patients, with the suit simply affixed over a user's normal clothes. Considering that it also offers multiple training modes, progressing its wearer from being unable to walk right through to various motor levels, and that Ekso has only been in operation since 2005, it's easy to see how the technology could transform lives.

Walking modes

First steps
A physical therapist controls the user's steps with button pushes, with the wearer supporting themselves with crutches.



Active steps
In the second stage, the user takes control of their limb movements through button pushes on a set of smart crutches.

Pro steps
In the most advanced stage, the exoskeleton moves the user's hips forward, shifting them laterally into the correct walking position.

Anatomy of the Ekso Bionic Suit

Check out the core components and features of this revolutionary exoskeleton

Power plant
The Bionic Suit is powered by a brace of high-capacity lithium batteries that can energise the exoskeleton for up to four hours.

Computer
A central computer system receives data from the Bionic Suit's 15 sensors to fine-control the user's leg movements.

Motors
Four electro-mechanical motors drive movement at the user's hips and at each knee.

Crutches
If needed, a set of smart crutches can be used by the user to control their leg movements with arm gestures.

Fixed assist
Each of the exoskeleton's legs is fitted with a fixed assist system that can contribute a fixed amount of power to help the user complete a step.

Joints
The exoskeleton's mechanised joints are designed to allow the user to bend their limbs as naturally as possible.

Pegs
Heel pegs help secure the wearer's feet and ensure they don't stumble while training on uneven ground.

Adaptive assist
Depending on the strength and capability of the user, the Bionic Suit can be adjusted to produce various smooth and natural gaits.

2004
TMSUK and Kyoto University reveal the T-52 Enryu, one of the first rescue robots to be used by Japanese emergency services.

2006
Japanese machinery and robotics manufacturer Sakakibara-Kikai produces the first genuine bi-pedal mech. The machine measures a huge 3.4m (11.2ft) tall.

2009
Lockheed Martin reveals its Human Universal Load Carrier (HULC), an exoskeleton purpose-built to be worn by US soldiers.

2011
Rex Bionics launches the Rex exoskeleton, a device that consists of a pair of robotic legs that can help people with paraplegia to stand and walk.

2013
Honda begins US trials of its Walking Assist Device at the Rehabilitation Institute of Chicago. The product aims to help stroke patients walk again.

Real-life spidey sense

Ever thought it would be cool to have the 'spidey sense' of *Spider-Man* in real life? Well, now you can, thanks to a neat research project undertaken by the University of Illinois. SpiderSense is a wearable device that, by manipulating the some of the millions of sensory receptors located on human skin, can relay information about the wearer's environment to them. This clever tech means that despite being blindfolded, the user would know exactly where they were in relation to moving objects.

The system works thanks to the SpiderSense's wearable tactile display, which consists of a series of sensor modules affixed to the user's arms and legs. As the user moves about a room, distance information regarding its objects are relayed to the user through the pads via increases or decreases in pressure, with the skin's receptors relaying that information to the brain. The sensor modules scan the environment using ultrasound, repeatedly sweeping an environment for objects and barriers in the way.

In terms of applications, technology like SpiderSense could be used to compensate for a dysfunctional or missing sense, such as visual impairment, or to augment someone's fully functional senses.

LAND WALKER

BATTLEMECH POWER

On the most extreme side of the mech revolution sits Sakakibara-Kikai's Land Walker, a 3.4-metre (11.2-foot) tall, 1,000-kilogram (2,200-pound) bipedal exoskeleton. Designed to replicate the battle mechs of popular science fiction, such as the AT-STs of the *Star Wars* films, the Land Walker is the world's first machine of its kind, capable of moving around on two feet, thunderously plodding around under the command of its human pilot. The Land Walker is powered by a 250cc four-stroke engine, can walk around at 1.5 kilometres (0.93 miles) per hour and is equipped with an auto-cannon capable of firing squishy rubber balls. Unfortunately, the Land Walker currently retails for £210,000 ($345,000), so it might be some time before you can stomp to work in one.

While the Land Walker's current performance arguably leaves a lot to be desired, with more development funding, a machine such as this could easily become the future of law enforcement, with its intimidating physical presence and – if armed correctly – damage-dealing capabilities more than a match for any civilian vehicle.

The Land Walker is still a novelty device but has great future potential

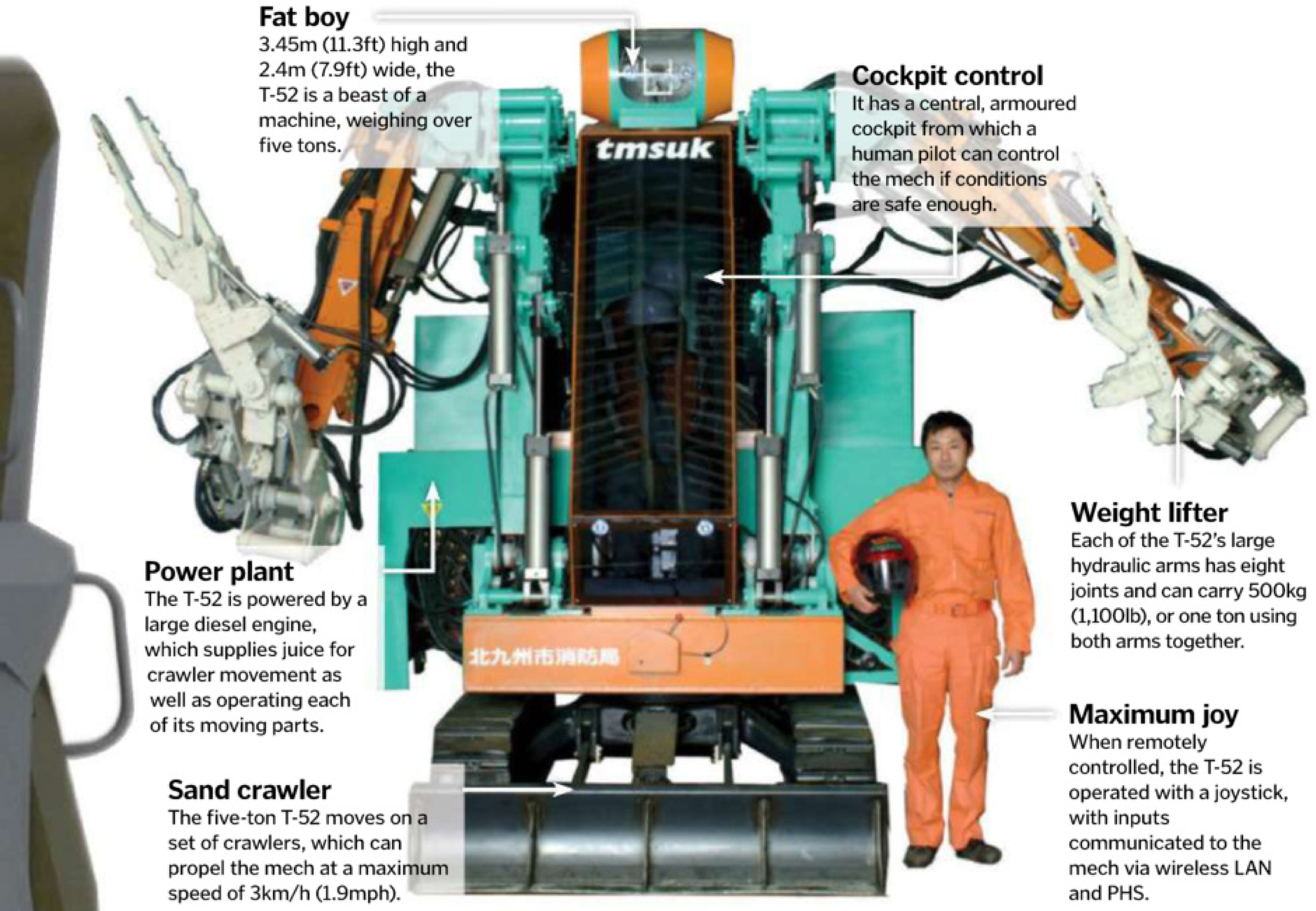
ENRYU

ROBOTIC RESCUE DRAGON

A large-scale, human-controlled robot for use in disaster sites, the T-52 Enryu (which translates as 'T-52 Rescue Dragon') is one heck of a piece of kit. At 3.45 metres (11.3 feet) tall and 2.4 metres (7.9 feet) wide, it's packed with seven 6.8-megapixel CCD cameras and the ability to lift objects weighing up to one ton with its hydraulic arms. The T-52 is arguably the most advanced disaster-relief mech in service, infiltrating hazardous areas and withstanding conditions a human never could.

The mech was built by the Japanese company TMSUK in partnership with Kyoto University and Japan's National Research Institute of Fire and Disaster for undertaking heavy-duty work in disaster areas. The T-52 can either be operated from its armoured cockpit or remotely from a control station, with the pilot receiving contextual information via a series of LCD displays.

The machine specialises in lifting large and heavy objects, meaning that it can easily help free people trapped in earthquake-generated building collapses. While the Rescue Dragon is still in its development phase, it has already passed a number of operational tests and was recently deployed to help clear up the Fukushima Daiichi nuclear plant disaster of 2011, patrolling the site and removing large pieces of radioactive rubble.



Fat boy
3.45m (11.3ft) high and 2.4m (7.9ft) wide, the T-52 is a beast of a machine, weighing over five tons.

Cockpit control
It has a central, armoured cockpit from which a human pilot can control the mech if conditions are safe enough.

Power plant
The T-52 is powered by a large diesel engine, which supplies juice for crawler movement as well as operating each of its moving parts.

Weight lifter
Each of the T-52's large hydraulic arms has eight joints and can carry 500kg (1,100lb), or one ton using both arms together.

Sand crawler
The five-ton T-52 moves on a set of crawlers, which can propel the mech at a maximum speed of 3km/h (1.9mph).

Maximum joy
When remotely controlled, the T-52 is operated with a joystick, with inputs communicated to the mech via wireless LAN and PHS.

The best of the rest

1 Kuratas
The ultimate executive toy, the Kuratas mech allows its owner to ride around in its futuristic cockpit while firing 6,000 BB rounds per minute from its dual, arm-mounted Gatling guns.

2 Cybernetic Anthropomorphous Machine
One of the first mechs ever built, the CAM was designed and built for the US Army in 1966 to move cargo and weapons across battlefields.

3 Sarcos XOS 2
An exoskeleton that grants its wearer superhuman strength, the XOS 2 is currently being trialled by the US Army, with a finished untethered variant set to enter service in 2020.

4 Body Weight Support Assist

Honda's Body Weight Support Assist from is a partial exoskeleton that, once worn, helps to support the user's upper body, taking some of its weight off their legs.

5 Raytheon Heavy Lifter
Designed to move large crates, containers and objects, the Heavy Lifter offers its user a high degree of freedom and agility.

6 Kid's Walker
The Land Walker's baby brother, the Kid's Walker – which costs about £12,000 ($20,000) – is designed to allow children to pilot their own toy mech while remaining safe.

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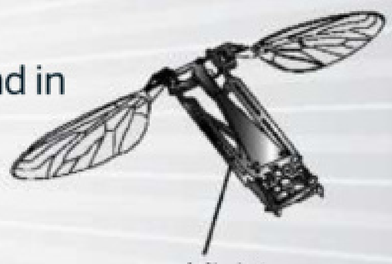
HOW IT WORKS BOOK OF AMAZING TECHNOLOGY Vol.3

GADGETS & FUTURE TECH

James Bond might be fiction, but advanced gadgets and futuristic inventions are definitely a reality. Find out just how close to home they are, and how soon you might use them yourself

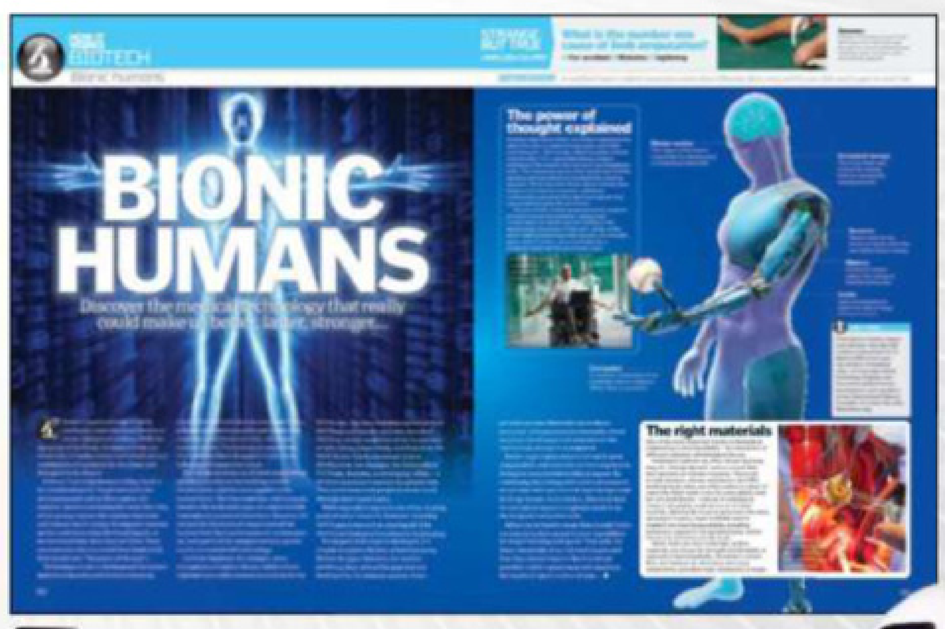
ENTERTAINMENT

The most sophisticated technology can be found in everyday items, including smartphones, game consoles and virtual reality, and even the standard computer mouse



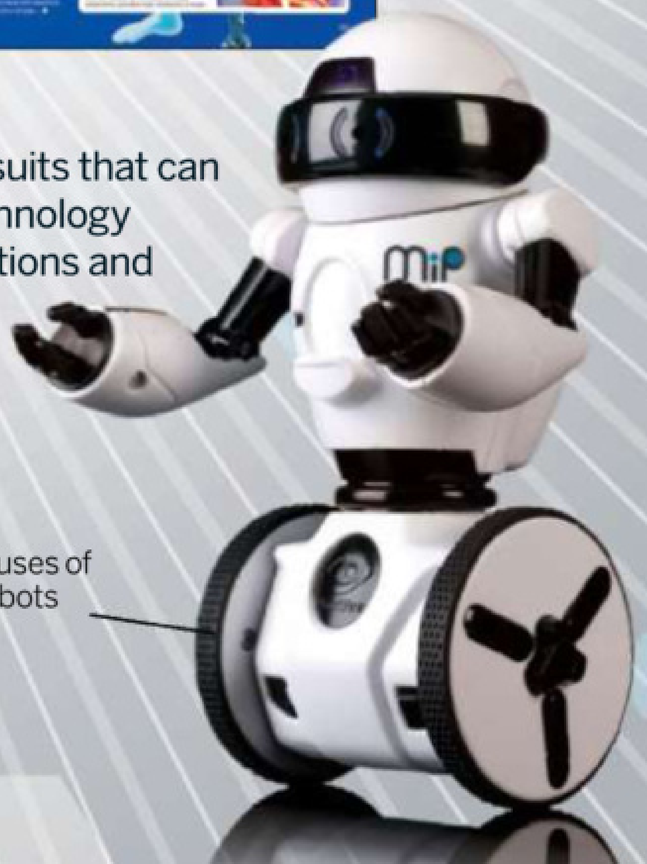
ENGINEERING

Learn all about the technology that goes into building humanity's most impressive creations, from elevated bridges and deep underground tunnels to the heights of the Empire State Building



BIOTECH

From 3D printed organs to Exo suits that can assist mobility, discover the technology that extends our biological functions and takes humanity even further



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