MANCHESTER
1824

The University of Manchester
Dalton Nuclear Institute

THE ENERGY GAME

Where does your power come from?

Contents

Printing instructions

To play the game using this digital version, print the 32 cards on pages 6 to 9.

How to play

1. Shuffle the cards and deal them all out, face down.
2. Players hold their cards in a face up stack, with only them being able to see their own.
3. The player to the left of the dealer begins, choosing one of the top of their pile and reading out the value. Each player then reads out the value for the same chosen attribute on their top card.
4. The person with the highest value for the chosen attribute wins and keeps all of the cards, putting them at the bottom of their pile. The winner can then choose the attribute for the next round.
5. Play continues until one player has all of the cards and is the winner of the game.

Ties

If a tie situation occurs, when two or more players have the same winning value, all players place their top card in the middle of the table and the turn remains with the same player who chose that attribute. The next player who wins the round of cards also collects the pile of cards from the middle of the table.

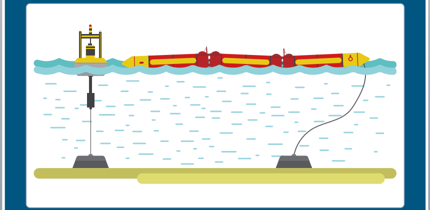
Variations

One variation is that players who have three or fewer cards left can look at them all and choose in which order to play them. This significantly lengthens the game.

Another variation is to choose your own card deck by laying out all the cards in the pack face up and then drawing lots to decide who gets first pick. This player can choose their first card. The person to the left of this player gets to pick the second card, and so on, until there are no cards left. The game is then played as per normal.

WAVE

RENEWABLES – HYDRO



Carbon saved	88 / 100
Energy density	16 / 100
Resource availability	95 / 100
Deployability	42 / 100
Reliability	27 / 100
Cost efficiency	24 / 100
Hydrogen production	14 / 100

Wave energy is captured by absorbing the up and down movement of water to generate electricity.

CONVENTIONAL HYDROELECTRIC

RENEWABLES – HYDRO

Carbon saved	95 / 100
Energy density	23 / 100
Resource availability	97 / 100
Deployability	80 / 100
Reliability	62 / 100
Cost efficiency	87 / 100
Hydrogen production	35 / 100

Hydroelectricity can be generated when water held behind a dam is passed through a turbine. Worldwide, hydroelectricity supplies more energy than all other renewable sources combined.

TIDAL BARRAGE

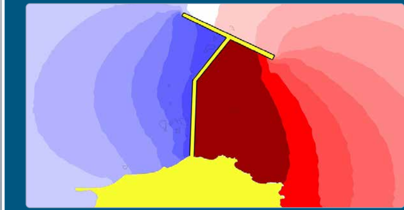
RENEWABLES – HYDRO

Carbon saved	82 / 100
Energy density	20 / 100
Resource availability	91 / 100
Deployability	51 / 100
Reliability	84 / 100
Cost efficiency	25 / 100
Hydrogen production	41 / 100

Tidal barrages built across a river or bay can generate electricity as the tide goes in and out. The environmental effects aren't known and it is very expensive to set up, but during high tides the energy can be stored in the barrage and released when needed.

TIDAL DYNAMIC

RENEWABLES – HYDRO

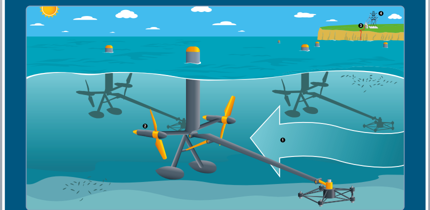


Carbon saved	78 / 100
Energy density	18 / 100
Resource availability	88 / 100
Deployability	14 / 100
Reliability	72 / 100
Cost efficiency	30 / 100
Hydrogen production	34 / 100

The tidal dynamic method is under development. It is based on the fact that by building a dam off the coast, electricity can be generated from the water level differences on either side of the dam (red – high, blue – low).

TIDAL STREAM

RENEWABLES – HYDRO



Carbon saved	84 / 100
Energy density	22 / 100
Resource availability	97 / 100
Deployability	50 / 100
Reliability	71 / 100
Cost efficiency	47 / 100
Hydrogen production	36 / 100

Tidal stream uses underwater turbines to generate electricity from the predictable and reliable movement of water. Tidal forces arise from the gravitational force of the moon and rotation of the earth.

CARBON CAPTURE BIOMASS

RENEWABLES – BIOMASS

Carbon saved	110 / 100
Energy density	6 / 100
Resource availability	84 / 100
Deployability	15 / 100
Reliability	90 / 100
Cost efficiency	59 / 100
Hydrogen production	89 / 100

By growing plants for use in biomass stations and then capturing the carbon released when material is burnt, it is possible to achieve a net negative carbon output.

BIOMASS

RENEWABLES – BIOMASS

Carbon saved	70 / 100
Energy density	6 / 100
Resource availability	84 / 100
Deployability	91 / 100
Reliability	93 / 100
Cost efficiency	79 / 100
Hydrogen production	59 / 100

Biomass energy is generated from living, or previously living things (e.g. alcohol, wood and waste). This may take land away from growing crops for food, so must be managed carefully.

GEOTHERMAL

RENEWABLES – GEOTHERMAL

Carbon saved	90 / 100
Energy density	10 / 100
Resource availability	79 / 100
Deployability	60 / 100
Reliability	90 / 100
Cost efficiency	84 / 100
Hydrogen production	49 / 100

Geothermal heat pumps use the heat energy stored in the earth to create steam which is used to drive turbines. This requires a large underground area as the energy density is very low. Unlike most renewables, geothermal energy has the advantage of not being intermittent.

OFFSHORE WIND

RENEWABLES – WIND

Carbon saved	85 / 100
Energy density	15 / 100
Resource availability	90 / 100
Deployability	90 / 100
Reliability	42 / 100
Cost efficiency	66 / 100
Hydrogen production	20 / 100

Offshore wind farms are more difficult to construct than their onshore counterparts, but the wind is stronger and more consistent at sea making them more reliable and able to generate around 50% more electricity than an onshore wind farm of the same size.

HIGH-ALTITUDE WIND

RENEWABLES – WIND

Carbon saved	92 / 100
Energy density	8 / 100
Resource availability	94 / 100
Deployability	7 / 100
Reliability	37 / 100
Cost efficiency	30 / 100
Hydrogen production	30 / 100

High-altitude wind is currently being developed as kites or lighter than air devices. These can reach high altitudes in places where there is always wind. None are yet at the stage where they are being used to produce energy.

DEEP-OFFSHORE WIND

RENEWABLES – WIND

Carbon saved	89 / 100
Energy density	25 / 100
Resource availability	90 / 100
Deployability	7 / 100
Reliability	44 / 100
Cost efficiency	28 / 100
Hydrogen production	24 / 100

Deep-offshore wind farms are designed as floating wind turbines. They are far from commercial deployment and only one is in use worldwide. Deep-offshore wind is very expensive compared to near-offshore wind.

ONSHORE WIND

RENEWABLES – WIND

Carbon saved	90 / 100
Energy density	10 / 100
Resource availability	92 / 100
Deployability	95 / 100
Reliability	29 / 100
Cost efficiency	77 / 100
Hydrogen production	14 / 100

In wind farms the kinetic energy from the wind is converted to mechanical energy. Many of the largest operating onshore wind farms are located in the USA. They are generally located in hilly or mountainous areas.

COAL

FOSSIL FUELS

Carbon saved	1 / 100
Energy density	60 / 100
Resource availability	10 / 100
Deployability	100 / 100
Reliability	90 / 100
Cost efficiency	85 / 100
Hydrogen production	1 / 100

Coal is the largest source of energy worldwide, being more abundant than other fossil fuels, but it produces the most waste and greenhouse gases per unit of energy produced. Coal was the fuel that powered the industrial revolution.

NATURAL GAS

FOSSIL FUELS

Carbon saved	10 / 100
Energy density	65 / 100
Resource availability	6 / 100
Deployability	95 / 100
Reliability	95 / 100
Cost efficiency	90 / 100
Hydrogen production	10 / 100

Natural gas comprises of a mixture of flammable gases. As with other fossil fuels, the burning of gas produces air pollutants, but produces half the amount of greenhouse gases than coal does.

OIL

FOSSIL FUELS

Carbon saved	3 / 100
Energy density	70 / 100
Resource availability	1 / 100
Deployability	95 / 100
Reliability	90 / 100
Cost efficiency	75 / 100
Hydrogen production	3 / 100

Oil can be used to generate electricity just like other fossil fuels. Today, oil is rarely used to generate electricity as it is better used to fuel vehicles. Some oil fired power stations do still exist, mostly in off-grid locations where oil is easier to transport and store.

CARBON CAPTURE COAL

FOSSIL FUELS

Carbon saved	55 / 100
Energy density	40 / 100
Resource availability	4 / 100
Deployability	25 / 100
Reliability	85 / 100
Cost efficiency	70 / 100
Hydrogen production	47 / 100

Capturing carbon released from coal fired power stations and storing it in depleted oil reservoirs can reduce their carbon emissions. This reduces CO_2 release but takes more energy which means natural resources are used less efficiently.

CARBON CAPTURE GAS

FOSSIL FUELS

Carbon saved	65 / 100
Energy density	47 / 100
Resource availability	2 / 100
Deployability	25 / 100
Reliability	95 / 100
Cost efficiency	73 / 100
Hydrogen production	62 / 100

Capturing carbon released from gas fired power stations and storing it can reduce carbon emissions. This reduces CO_2 release, but requires more energy which means natural resources are used less efficiently.

MOLTEN SALT STORAGE (SOLAR)

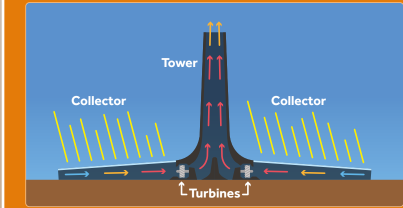
RENEWABLES – SOLAR

Carbon saved	60 / 100
Energy density	23 / 100
Resource availability	97 / 100
Deployability	20 / 100
Reliability	60 / 100
Cost efficiency	2 / 100
Hydrogen production	22 / 100

The molten salt storage method for concentrating solar power uses reflective mirrors to direct sunlight at molten salt to store heat energy. The stored heat energy can be used to generate electricity even when the sun is not shining.

SOLAR UPDRAFT TOWER

RENEWABLES – SOLAR



Carbon saved	50 / 100
Energy density	2 / 100
Resource availability	90 / 100
Deployability	10 / 100
Reliability	10 / 100
Cost efficiency	1 / 100
Hydrogen production	3 / 100

Solar updraft towers use large areas of greenhouse structures to heat air which flows up a chimney via a turbine to generate electricity. The very large areas required are not entirely lost as they can be used to grow plants too.

CONCENTRATED SOLAR

RENEWABLES – SOLAR

Carbon saved	60 / 100
Energy density	25 / 100
Resource availability	95 / 100
Deployability	30 / 100
Reliability	30 / 100
Cost efficiency	10 / 100
Hydrogen production	11 / 100

The concentrated solar method uses lenses or mirrors to focus a large area of sunlight onto a small area to generate steam for powering a turbine as the light is converted to heat. This is good for large areas with lots of sunlight, but not effective when dark.

PHOTOVOLTAIC

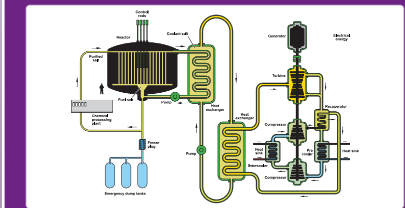
RENEWABLES – SOLAR

Carbon saved	75 / 100
Energy density	33 / 100
Resource availability	95 / 100
Deployability	80 / 100
Reliability	30 / 100
Cost efficiency	2 / 100
Hydrogen production	9 / 100

Photovoltaic cells convert energy from the sun directly into electrical energy. This is more economical in areas with lots of sunlight but, it also requires a lot of land.

MOLTEN SALT REACTOR

NUCLEAR FISSION

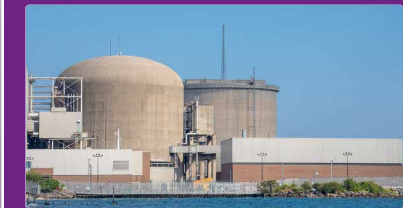


Carbon saved	95 / 100
Energy density	84 / 100
Resource availability	88 / 100
Deployability	5 / 100
Reliability	95 / 100
Cost efficiency	59 / 100
Hydrogen production	80 / 100

An MSR reactor can use thorium instead of uranium (more abundant than uranium in the earth's crust) where the fuel makes up a liquid molten salt. This has several advantages over non-liquid fuel based reactors but is much less developed.

CANDU REACTOR

NUCLEAR FISSION

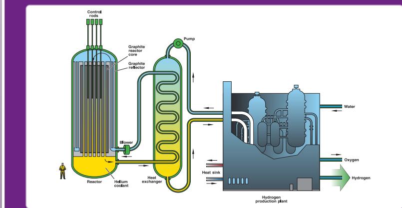


Carbon saved	86 / 100
Energy density	75 / 100
Resource availability	53 / 100
Deployability	88 / 100
Reliability	90 / 100
Cost efficiency	79 / 100
Hydrogen production	46 / 100

The CANada Deuterium Uranium reactor uses natural uranium fuel with heavy water as a moderator and coolant. Heavy water replaces the hydrogen in water with slightly heavier deuterium, which permits the use of unenriched fuel.

HIGH TEMPERATURE GAS-COOLED REACTOR

NUCLEAR FISSION



Carbon saved	90 / 100
Energy density	85 / 100
Resource availability	65 / 100
Deployability	20 / 100
Reliability	95 / 100
Cost efficiency	77 / 100
Hydrogen production	80 / 100

In a HTGR, fuel is embedded in graphite which is incredibly hard. This fuel form makes this reactor type inherently safe and allows the reactor to shut itself down with no human intervention.

MAGNOX REACTOR
NUCLEAR FISSION

Carbon saved	80 / 100
Energy density	74 / 100
Resource availability	50 / 100
Deployability	95 / 100
Reliability	66 / 100
Cost efficiency	74 / 100
Hydrogen production	32 / 100

Magnox reactors were the first commercial scale reactors in the world for producing electricity. They use CO_2 as a coolant, unlike most reactors deployed today which use water. The Magnox name comes from the cladding of the fuel "MAGnesium Non-OXidising".

SMALL MODULAR REACTOR
NUCLEAR FISSION

Carbon saved	85 / 100
Energy density	90 / 100
Resource availability	57 / 100
Deployability	70 / 100
Reliability	95 / 100
Cost efficiency	80 / 100
Hydrogen production	60 / 100

SMRs are nuclear plants designed to be smaller than traditional nuclear power stations. Because of their reduced size, they can be built in a factory then shipped and assembled on site, reducing building costs.

PRESSURISED WATER REACTOR
NUCLEAR FISSION

Carbon saved	82 / 100
Energy density	85 / 100
Resource availability	60 / 100
Deployability	95 / 100
Reliability	95 / 100
Cost efficiency	79 / 100
Hydrogen production	55 / 100

PWRs are the world's most common type of nuclear reactor. Water is kept under pressure (to prevent it from boiling) and removes the heat from fuel to generate steam in the steam generators.

ADVANCED GAS REACTOR
NUCLEAR FISSION

Carbon saved	75 / 100
Energy density	78 / 100
Resource availability	55 / 100
Deployability	80 / 100
Reliability	65 / 100
Cost efficiency	79 / 100
Hydrogen production	34 / 100

AGRs are the second generation of UK gas cooled reactors. They operate at higher temperatures than Magnox reactors to increase efficiency. Carbon dioxide is used as a coolant.

BOILING WATER REACTOR
NUCLEAR FISSION

Carbon saved	82 / 100
Energy density	85 / 100
Resource availability	60 / 100
Deployability	95 / 100
Reliability	93 / 100
Cost efficiency	79 / 100
Hydrogen production	46 / 100

In a BWR the fuel is used to directly generate steam (unlike a PWR) which drives a turbine. This is the second most common reactor type after the PWRs, but there are none in the UK.

LIQUID METAL FAST REACTOR
NUCLEAR FISSION

Carbon saved	95 / 100
Energy density	94 / 100
Resource availability	90 / 100
Deployability	20 / 100
Reliability	50 / 100
Cost efficiency	59 / 100
Hydrogen production	65 / 100

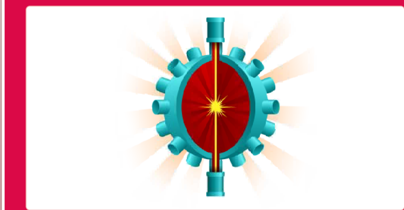
LMFRs use a metal coolant and can be used to breed more than they use, making them very sustainable. This may become more important as uranium reserves run out. They also have the potential to use long-lived radioactive waste as fuel.

MAGNETIC CONFINEMENT FUSION
NUCLEAR FUSION

Carbon saved	97 / 100
Energy density	100 / 100
Resource availability	98 / 100
Deployability	3 / 100
Reliability	15 / 100
Cost efficiency	5 / 100
Hydrogen production	10 / 100

Nuclear fusion creates energy by fusing atoms together – the same reaction that happens inside the sun. This approach uses magnetic fields to hold fuel that is so hot that it would otherwise destroy any material it touches. This is the most well developed aspect of fusion power.

INERTIAL CONFINEMENT FUSION
NUCLEAR FUSION



Carbon saved	97 / 100
Energy density	100 / 100
Resource availability	98 / 100
Deployability	1 / 100
Reliability	10 / 100
Cost efficiency	2 / 100
Hydrogen production	1 / 100

Inertial confinement fusion uses lasers to compress fuel until it becomes so hot that its atoms begin to fuse. This approach has many decades of research to go before it can be said to be a viable source of energy.

Attributes

Attributes are shown as a score out of 100 on the playing cards. Scoring shows how each technology performs against the others for each attribute: the higher the score, the better the performance. However, the scores have been scaled to make the game more playable. Many of the attributes encompass multiple qualities and some technologies are still underdeveloped, making precise scoring difficult. Read on for further details about each attribute.

NB. Unless otherwise stated the following text covers the more common technologies: e.g. pressurised water reactors (PWRs) and boiling water reactors (BWRs) for nuclear power; coal and gas for fossil fuels and solar PV, onshore wind and hydro for renewables. Other technologies are les commonly used or not commercially available.

Carbon saved

This is a measure of how each technology can contribute to reducing our carbon footprint. It takes into account lifecycle emissions from fuel, construction, transport and waste. A higher number reflects a bigger carbon saving.

Many studies have calculated the carbon footprint of power generating technologies per kWh (kilowatt hour) of electricity produced, both across the world and within the UK.

Energy density

This is a measure of how much electricity a technology can generate in a given area. It takes into account facility size and the land required to mine fuel and to dispose of waste.

High energy density is required for counties with a high population density like the UK. Renewables require a lot of raw materials to construct a facility and a lot of land to operate, but they do not require the mining of fuel. Fossil fuels require a small area of land and small facilities but vast quantities of fuel. As renewables are not energy dense enough to provide all of the UK's electricity, they have been given a lower score than fossil fuels and nuclear power.

Resource availability

This is a measure of how long natural resources will last to fuel and build each different type of facility. Some energy sources, such as fossil fuels, have a limited fuel supply, whereas others are completely renewable and depend only on the material requirement to build facilities.

Fossil fuels and current nuclear fission reactors have a limited fuel supply, expected to last a few hundred years. Advanced nuclear fission reactors, such as fast breeder reactors, can use nuclear fuel more sustainably, lasting several thousand years. Fusion and renewables have an unlimited fuel supply, their sustainability is based on their energy density and the raw materials required to build facilities.

Deployability

This is a measure of how developed a technology is – i.e. how close it is to being used or how extensively it has already been used. Some systems have been used on a large scale, others aren't yet commercially developed. Some are commercially available but are unlikely to be mass produced by private industry due to prohibitive issues such as cost efficiency.

Deployability is hard to quantify. Scores are based on the scale to which each technology is in operation, or is close to being in operation, across the world. Advanced technologies which have not been commercially developed (e.g. fusion, high altitude wind) have the lowest score.

Reliability

This is a measure of how consistent energy production is. Some systems are constant as they have a constant supply of fuel (e.g. fossil fuels, nuclear power), others are intermittent based on factors like the weather (e.g. renewables). Scores also account for the probability of breakdowns and the need for offline maintenance.

Scores are based on the maximum possible capacity factors of each technology. These may change over time. Some energy sources, such as fossil fuels, have the potential for very high capacity factors, but may not be used if more sustainable energy sources are available, such as renewables. Scores assume that underdeveloped energy sources (e.g. fusion) would be less reliable when first operated.

Cost efficiency

This is a measure of the average cost of a unit of electricity over the lifetime of a facility. This takes into account the cost of construction, operation, fuel, decommissioning and waste disposal.

The higher the score, the cheaper a technology is for producing electricity. The cost of energy sources changes over time based on fuel costs, taxation and technology development. Scores are based on UK estimates for new power plants

Hydrogen production

This is a measure of how much hydrogen the different energy sources could produce. Hydrogen can be used to power vehicles, generate electricity and heat homes. This score was calculated by weighting residual carbon emissions, efficiency and availability for the different technologies.

Find out more

More learning resources are available at
www.dalton.manchester.ac.uk/engage

Order more packs of this game