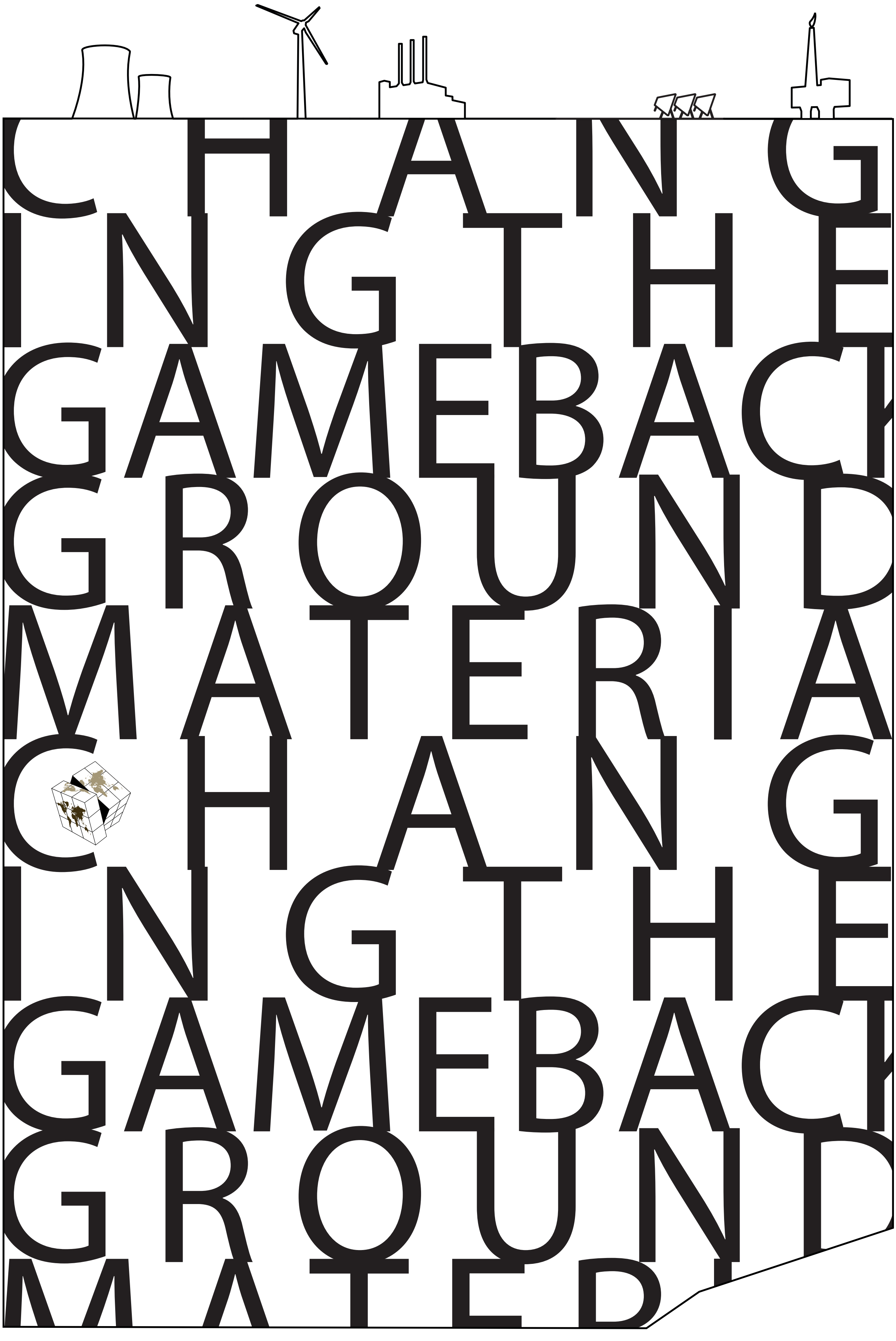


CHANGING THE GAME BACKGROUND MATERIAL

ENERGYCROSSROADS
the global coalition for a clean, prosperous and secure energy future

CHANGING THE GAME BACKGROUND MATERIAL

INTRODUCTION

Welcome to *Changing the Game*, developed by Energy Crossroads with the help of energy experts from EA Energy Analysis. We hope it will spur discussion and contribute to greater understanding of the energy challenges and opportunities that lie before us. The purpose of this game is to let you decide how the European energy system should develop, right now and into the future. You may have dreams and ideas of how things should move forward. We are now giving you the chance to try and make them come true.

WHAT IS *CHANGING THE GAME*?

The aim of any energy system is to provide reliable and secure energy to all consumers. At first glance, this may seem like a relatively simple task. In reality there are a complex set of limitations that constrain an energy system's structure and effectiveness. Common constraints include engineering limitations, concerns for the environment, costs and political considerations. Until now, these constraints were hidden in engineering reports, budgets and legislation. *Changing the Game* is designed to de-mystify the energy planning and policy development process. It inspires and facilitates an informed discussion about the future of our energy. *Changing the Game* translates words and numbers into a visual representation expressed in LEGO® bricks. Each LEGO® brick has a color and size that corresponds to essential planning elements such as energy resource types, and CO_2 emissions.

The purpose of this background material is to explain these and other basic elements of energy system planning. To begin with, we will give you an outline of the game. Essentially, *Changing the Game* is split into two parts: day one and day two. Day one concentrates on engineering and economic possibilities and limitations. It is important to understand these concepts before thinking more broadly about sociopolitical effects during day two.
During day one, you will be put in charge of one of four European regions. You will start out by setting your own targets, and then continue towards building a scenario for your region's energy system in 2030 representing all energy aspects shown with LEGO® towers. *Changing the Game* includes a number of Change Cards which you can decide to implement. By the end of the day, having applied some of the possible changes, you will have created a realistic scenario that resembles your dreams. You will have planned an energy system that is entirely plausible by 2030, complete with a price tag.

In practice, energy systems are changed by implementing policies that may affect a wide range of stakeholders. Therefore, on day two, you will consider the political and social effects of the system you designed on the first day. To do this, you will negotiate the most important changes you chose to implement on day one. Given social and political considerations, you now have the opportunity to develop an energy action plan on how to turn your energy scenario into reality. This requires thinking about who the policies are likely to affect and how. Possible stakeholders include governments, energy providers, industry, consumers and communities, as well as many others. In particular, we hope you can think of ways in which the young generation will be affected and can contribute to implementing your plan.

Two days of work, cooperation and playing with LEGO® bricks will result in a carefully considered and practical plan for Europe's energy future towards 2030. This plan will include specific policies that, with sufficient political and popular will, could be implemented in the near future.

Changing the Game is not just a game; it is a vision and petition for change. For this reason, the energy action plan booklet includes a page for you, at your discretion, to sign as support for the plan you created. *Changing the Game* is your opportunity to gain insight and create solutions to a clean, secure and prosperous energy future.

THE MODEL BEHIND *CHANGING THE GAME*

Changing the Game is based on a simplistic model of the energy system that, although being a very crude approximation to reality, still captures the basic principles of energy systems. It shows and reflects the most typical options and limitations in planning energy systems.

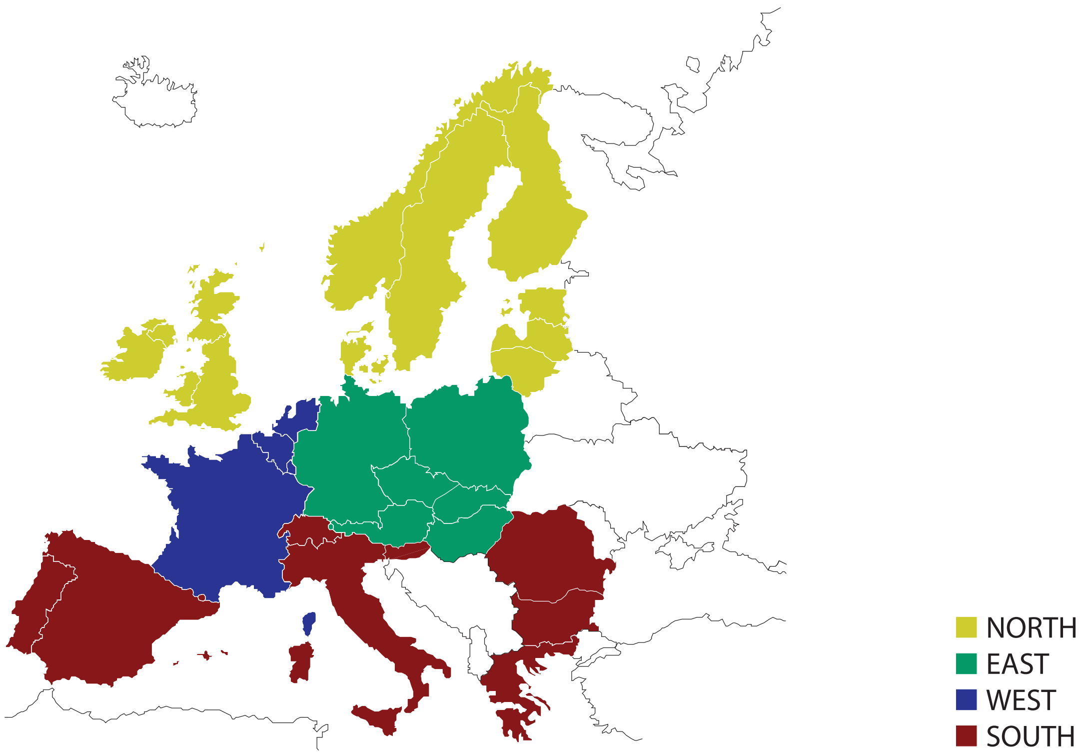
At this time we should emphasize that the simplifications used to create the game are aimed at didactic simplicity, therefore the extent to which a system can be altered is limited. Yet, we are convinced that the boundaries we created reflect the right tendency of what will be feasible for an energy system in 2030. Please note that we kept the number and kinds of possible changes you can make relatively low and based on technologies that are currently feasible or likely to be so in 2030.

Because of that, there is no reason to despair if you can't reach your ambitious targets within the frame of this game. Instead we hope you will be motivated to contribute with your own creativity, to make a difference for the future!

REGIONS IN THE GAME

To make energy planning simple, it would be easiest to put everyone into one box. On the other hand, there are large regional differences in culture, consumption patterns and renewable energy potentials. Furthermore, the distances, over which electricity can be feasibly transported, are limited. Therefore we have split Europe into four regions with about the same energy consumption and population. The four regions are shown below.

In *Changing the Game* you will be put in charge of transforming the energy system for one of these regions:



ABOUT THIS BACKGROUND MATERIAL

The remainder of this document will provide you with the background necessary for enjoying the game and appreciating the physical meaning of what you are dealing with. We sincerely hope that you will feel you are rethinking the future energy system and not simply playing a game about LEGO® bricks. This document will introduce you to a few basic concepts that you should be familiar with before playing the game. These concepts are summarized at the end of this background material.

Don't worry if there are concepts that you do not understand! You will be playing the game with participants of mixed backgrounds, and there will certainly be someone in your group who can explain what is unclear. Furthermore, there are energy experts available in case any questions arise. Throughout the document various general concepts related to energy systems planning will be introduced. How the concepts are used in the game is explained in the boxes following each chapter.

The Background Material is organized in two main chapters, entitled *Energy* and *Power*, in accordance with the structure of Day I in the game. The *Energy* chapter deals with how energy is used in the different sectors of society, and how energy use can be changed. The *Power* chapter focuses on electricity, introducing the technical difficulties that arise because electricity needs to be delivered and consumed exactly when it is produced.

ENERGY

Dealing with energy planning requires some insight into the basics of energy. Since the background of the participants playing the game is very broad, we will now review some of the basic concepts for energy planning to make sure everyone is on the same page.

This chapter is divided into two main sections; the first deals with the basics of energy, and the second with the planning of energy systems.

UNDERSTANDING ENERGY

ENERGY FORMS

Energy comes in many forms: *heat, motion, electrical, chemical* (as fuels or food), etc. The form of energy found in nature is called *primary energy.*

Natural gas is an example of a primary energy resource. It can be burned at a power plant to produce electricity and heat, in an engine to produce motion or in a home to produce heat only. In these ways, it is converted to the type of energy that we need.

ENERGY CONVERSION

We use energy in many ways; for example to heat our homes, to drive our cars, and to create light or sound. In order to use it, primary energy needs to be converted into a useful form of energy like heat, motion or electricity.

This conversion (almost) always comes with an energy loss in form of low temperature heat. That is, every time we convert energy from one kind to another we produce waste heat. For example, in incandescent light bulbs only 2.5% of the electricity is converted into visible light, the rest is turned into heat.

The ratio of the useful energy output and the primary energy input is called the conversion efficiency. As described above, the efficiency of incandescent lightbulbs is very poor.

CONTROLLABLE AND UNCONTROLLABLE PRIMARY ENERGY

You are probably familiar with distinguishing between fossil fuels and renewable primary energy. In energy system planning we like to use a slightly different grouping as well: *controllable* and *uncontrollable* primary energy.

The *controllable* energy resources include fossil fuels, uranium, biomass and water for hydro power. These we can easily store in the primary energy form and use when we want to. This is not the case for *uncontrollable* resources like wind, sun and waves, which have to be used when they are available, or are otherwise lost.

ELECTRICITY

The electricity from our power plugs is not primary energy. However, it has a special role, because it is so easy and efficient to transmit and to convert into other forms of energy (e.g. motion, heat, chemical, light). It has to be generated from primary energy resources.

Today, most electricity production is done in so-called thermal power plants. The primary (chemical) energy of a fuel is converted into heat by burning it, using the heat to boil water and then running the steam through a turbine connected to a generator. In this process, between one half and two thirds of the initial primary energy is lost as low temperature heat (waste heat).

More advanced combined heat and power plants collect the waste heat and use it for a secondary purpose, such as district heating. This raises the overall efficiency tremendously, since two useful energy outputs can be provided with the same energy input: heating homes and supplying electricity.

Many other technologies use primary energy more directly. This is possible where the primary energy is motion (e.g. wind, hydro and wave power). Other ways of generating electricity directly are fuel cells and solar cells (solar photovoltaics).

ENERGY UNITS

Energy is often measured in Joules (J) or kilo Watt hours (kWh) and to some extent still in kilo calories (kcal - as you may know from food declarations).

Since energy systems planning on a regional scale deals with very large quantities of energy, consumption is usually calculated in PJ (Peta Joules), where 1 PJ = 1,000,000,000,000,000 J

Electricity is often given in TWh (Tera Watt hours), where 1 TWh = 1,000,000,000 kWh.

POLLUTION

Energy production has an impact on the environment. Burning fossil fuels releases CO_2 and other pollutants into the atmosphere causing acid rain and smog. Wind farms and hydro plants have a visual impact and take up land. Nuclear power results in long-term radioactive waste.

Cars and trucks create noise and local air pollution. Stoves in houses produce particles emitted into the neighbourhood.

These effects and many others should be taken into account when modeling and planning energy systems.

FUEL BRICKS + POLLUTION

In the game we have chosen to represent the different primary energy sources by LEGO bricks. Each energy resource has its own *colour.*

One fuel brick (coal, oil, natural gas, biomass) corresponds to 125 PJ of primary energy used per year. This is an enormous amount of energy. The total energy consumption of Denmark is equivalent to about 6 fuel bricks.

All fuel bricks are equivalent on a primary energy basis. The bricks representing the remaining energy resources (wind, nuclear, solar, etc.) are equivalent to the fuel bricks on an electricity output basis. Each electricity brick corresponds to an electric output of 17.5 TWh, which is the amount of electricity you get by converting 125 PJ of fuel into electricity in a power plant with 50 % efficiency.

Furthermore, information on the CO_2 emission of a fuel is given by the width of the brick. As a rule of thumb, the ratios of CO_2 emissions that result from producing the same amount of energy by burning coal, oil and natural gas is 5:4:3. This means that for the same amount of energy, the CO_2 emission from burning coal is about 25 % higher than for oil. Burning natural gas releases about 25 % less CO_2 than burning oil.

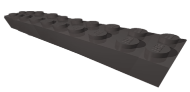
The emerging technology of carbon capture and storage (CCS), which can be added to coal fired power plants, reduces emissions to about 10-20 %. It is impossible to clean the flue gas (smoke) from CO_2 completely by using CCS. However, the emissions from CCS coal will be shown as zero in the game.

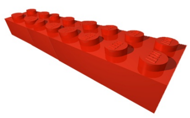
Two pieces of information are contained in each brick

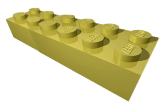
1. The colour of the brick indicating the energy resource
2. The width of the brick indicating the CO_2 emission. This only applies to coal, oil and gas, which are 2x10, 2x8 and 2x6 bricks respectively. All other energy resources (including CCS coal) are assumed to be carbon-neutral. Since having a 2x0 brick is not feasible these will be represented by 2x4 bricks.

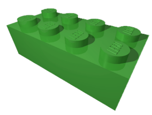
In the game we will only account for CO_2 emissions. However, we strongly encourage you to take into consideration other types of pollution as well.

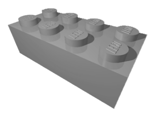
FUEL LEGO® BRICKS:


Coal

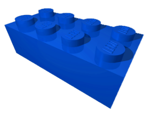

Oil

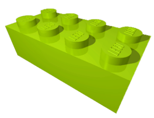

Natural gas


Biomass

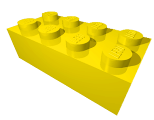

Coal w/ CSS

LEGO® BRICKS WHICH CAN ONLY BE USED FOR ELECTRICITY PRODUCTION:


Water


Uranium


Wind/Wave


Sun

DEALING WITH ENERGY

Energy planning is the exercise of creating a scenario for how we will use energy in the future.
Scenarios are created,to determine what is needed to fulfill, for example, certain politically set targets, or to estimate the consequences of reaching these targets.
In the process of creating these scenarios, a large number of assumptions are worked out about what technologies will be used and how, also including the behavior of energy users. Here we introduce a few basic notions that help thinking about energy scenarios.

ENERGY SERVICES

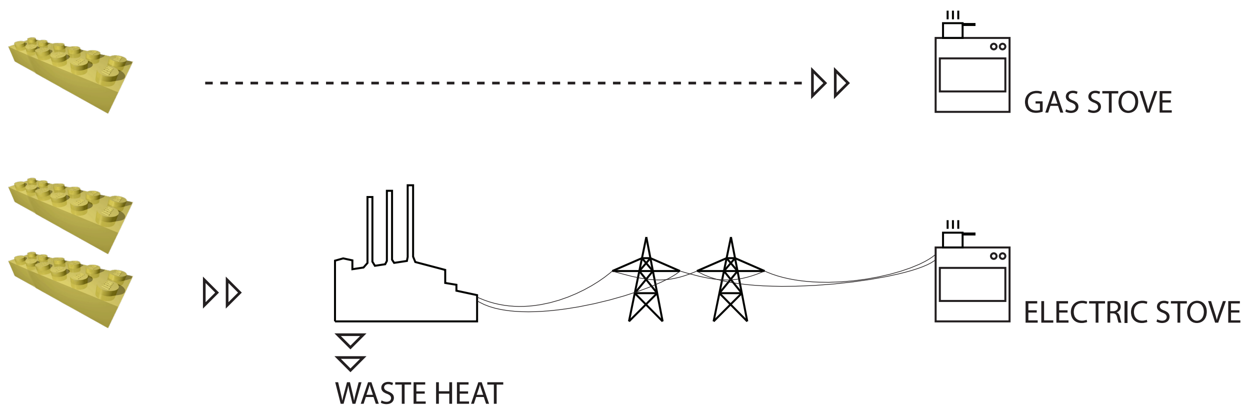
Let's start by recognizing that we need energy for just about everything we do, from heating our homes and running our cars to powering our electronics. These are all so-called energy services that we enjoy.

The energy we use, however, must come from somewhere. Energy system planning is all about finding ways to map the various energy resources found in nature to the energy services we require for our society.

These services can often be provided in many different ways. For example, keeping a comfortable indoor temperature could be done by burning wood in a stove, running district heating water through a radiator or using electric heating. But, to a large extent, it could also be done by insulating our houses. What one needs to keep in mind is that real comfort does not depend on the amount of energy we use to heat our homes, but the temperature we like to experience.

ENERGY EFFICIENCY

Energy efficiency of a process is defined as the ratio of useful energy output to the energy input. Useful energy is the energy in the desired form (light, heat, motion, etc.). Energy cannot disappear, so the "lost" energy is converted to low temperature heat, which is a low quality form of energy. As an example, consider the figure below illustrating two ways of cooking a meal. When cooking your meal by burning natural gas in a gas stove you use half the primary energy compared to the amount used when cooking on an electric stove using electricity generated at 50% efficiency.



How much energy we need to be able to provide a certain service level comes down to how efficiently we use that energy. If a house is poorly insulated, we must burn a lot of fuel to keep it warm, whereas a well insulated house does not need much heating. When doing energy planning, it is important to keep in mind that it is the energy service level that is important to people, not the energy consumption level. Adding a more efficient engine to a car, for example, will result in better fuel economy, which means a driver gets the same distance (same service level) but uses less energy (as fuel). Because of increased efficiency, the service level during the last centuries has been able to rise tremendously, with a far more modest rise in energy consumption.

Energy planning deals with changing both how we use energy and how we provide it. Sometimes using energy in a more intelligent way may be a better solution than just providing more of it.

Energy Sectors

In order to discuss what actions could be taken to change the energy system, it is a good idea to split energy use into sectors. This provides transparency of where and for what services energy is used. Also this allows an overview of what energy resources are used for what purposes. Separate political targets are usually set for each of the sectors and for the entire society as a whole.

THE THREE FUEL TOWERS AND THE ELECTRICITY CONSUMPTION TOWER

Three fuel towers comprised of fuel bricks (coal, oil, natural gas and biomass) represent the primary energy use in three sectors: transportation, heating and industry. Fuels that are being burned in the respective sectors are accounted for. If the fuel energy is provided indirectly through electricity it will be accounted for in the electricity tower.

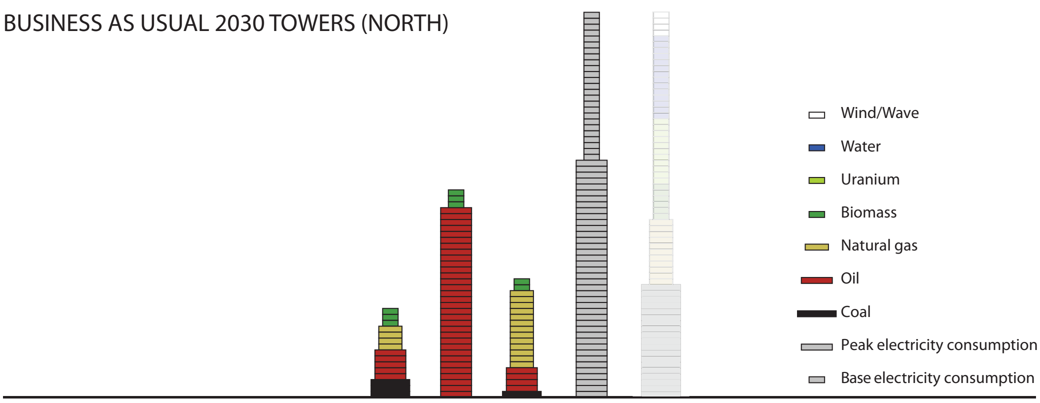
INDUSTRY
Primary energy used for energy purposes in industrial processes.
This mainly covers fuels used to provide high temperature heat for various purposes.
The use of fuels as chemicals (e.g. natural gas to produce ammonia) is not included.

TRANSPORTATION
All primary energy used to transport persons and goods is shown in this tower.
The energy consumed here is primarily gasoline and diesel for cars and trucks, and fuel for airplanes.

HEATING
Primary energy used to heat buildings.
This could be gas or oil for boilers and charcoal and wood to be burned in stoves.

THE ELECTRICITY CONSUMPTION TOWER
The number of bricks in this tower keeps track of the total electricity consumption in society.
This implies that the energy use of e.g. electric vehicles, electric heating and electricity used in industry is shown here.
The bricks in the electricity consumption tower are all grey, with different width to distinguish 'base and peak' electricity (explained in a later box), since the only purpose of this tower is to account for the consumption of electricity, not how it is generated. The electricity production tower introduced in the next section shows how the electricity is provided.
Note that since all bricks are equivalent on an energy basis the height of the tower is showing the total energy use in that sector.

BUSINESS AS USUAL 2030 TOWERS (NORTH)



CHANGE CARDS

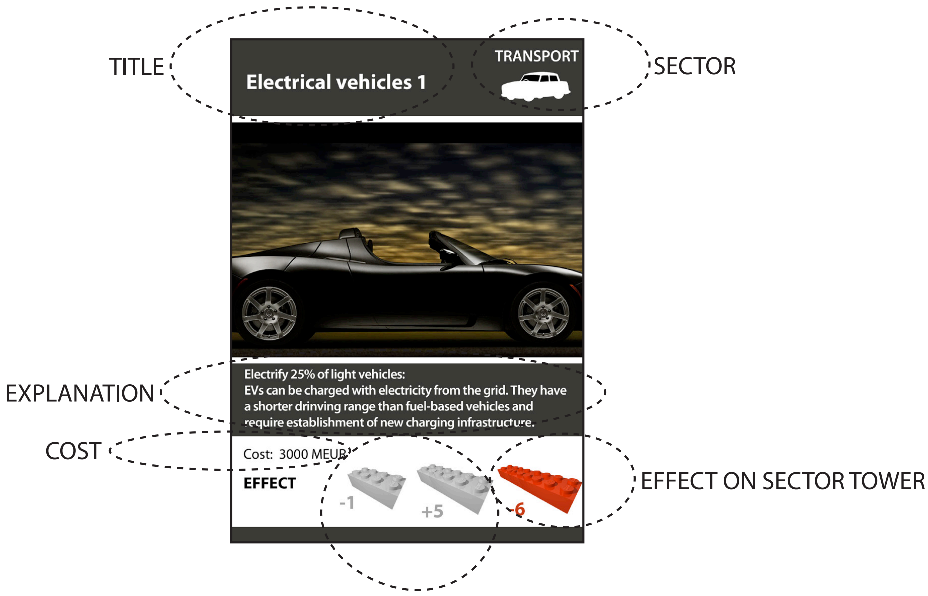
Changing the Game works by allowing you to apply changes to a given scenario for 2030. This scenario is called BAU2030 (business as usual). The BAU2030 scenario is a baseline scenario for your region that shows the resulting future if continuing current trends in population, economy, technology and human behavior.

The change cards show the effect of changing the technologies we use or our behavior.
Generally three types of changes are possible:

1. Changing the service level provided (behavioral changes)
2. Changing the energy efficiency of providing a given service
3. Changing the energy input to provide a given service

A change card is shown below. Following a short description of what the change implies the cost of the change is listed. This is the technical cost of carrying out the change. There may be other costs associated with the change (e.g. social costs, loss of convenience, loss of personal freedom), but these are not included. We urge you to discuss these costs as well.

Lastly the effect on the energy system is shown. Implementing a change implies changing the tower to which the card applies and possibly to the electricity consumption tower. This is done by moving bricks around.



POWER

Power relates to energy as flow relates to volume. That is, power is energy per time. This concept can be easily explained with an analogy of water, where power relates to energy as water-flow out of a tap into a bucket.

Whereas fuels can be stored until needed (e.g. gasoline in a cars tank), electricity needs to be used in the moment it is produced. This puts additional constraints on electricity systems since consumption and production need to match each other all the time. Providing sufficient energy is not enough – the power balance must be kept.

Following the analogy, we will talk about flow, piping and valves of the energy system in this chapter. Again, it is very expensive to build buckets for electricity (like big batteries), and therefore electricity cannot be stored on a large scale.

ELECTRICITY GENERATION

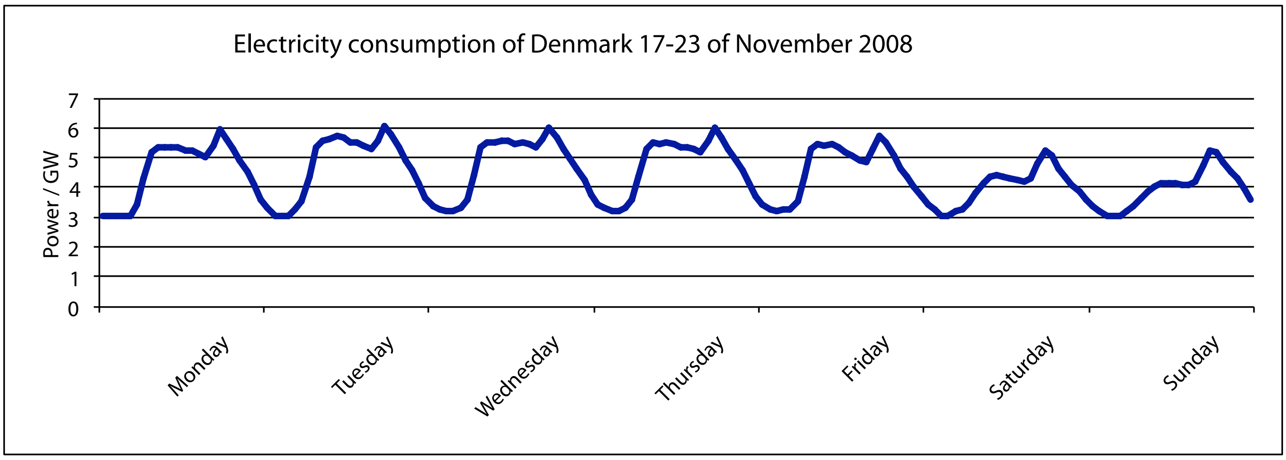
Today, most of the world's electricity is generated in power plants by burning fuels or splitting uranium. Renewable electricity generation is mostly done by running water through a turbine in a hydroelectric dam, and to a smaller extent by harnessing the wind with a wind turbine or the sun with solar cells.

For all these technologies you need both a primary energy input and the *capacity* to transform it into electricity. Capacity is the term used to describe a power plants ability to produce power. The capacity of a power plant is equal to the maximum power output.

Therefore, one needs to take into consideration both the cost of the capacity (power plant) and the cost of the fuel when deciding upon which electricity generation technologies to use. Capacity costs and fuel costs differ substantially between technologies. Fuel costs range from zero (wind, sun, water) to the high cost of natural gas.

ELECTRICITY CONSUMPTION

Now, when you have paid the cost to build a power plant and have the option of using it all the time, why wouldn't you? As mentioned above, you can only produce electricity if there is someone else to take it, because it cannot be stored. Our electricity consumption is not constant. In fact, it varies throughout the week as illustrated in the figure below. Demand is also subject to yearly variations due to changes in daylight hours, outside temperature, leisure time activities etc.



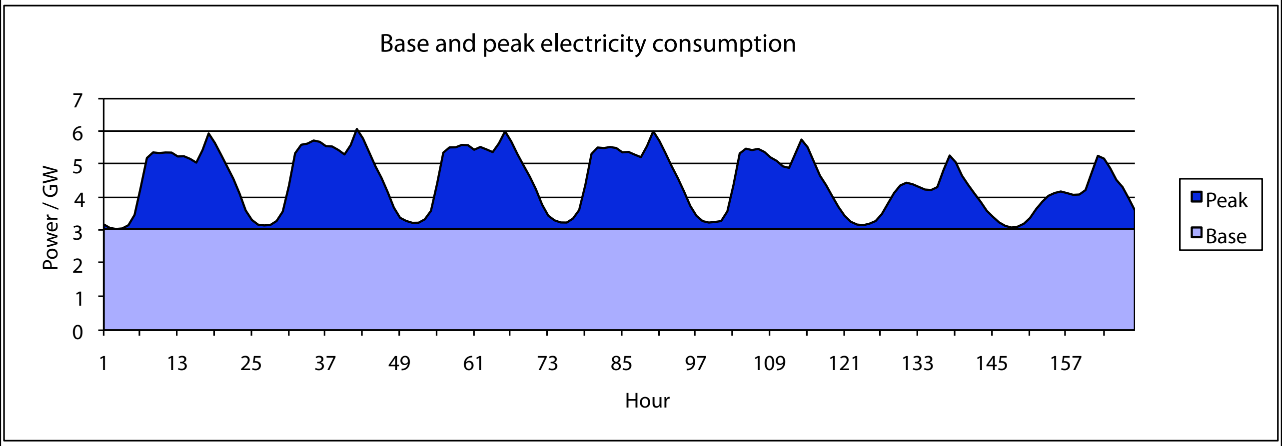
The level of demand variation puts constraints on what electricity generation technologies can be used. Why this is, will be addressed in the following sections.

BASE AND PEAK ELECTRICITY BRICKS

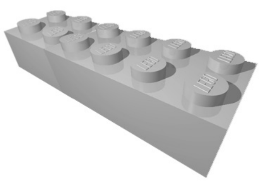
The electricity *consumption* tower consists of two types of electricity consumption bricks: Base Electricity (BE) and Peak Electricity (PE).

- BASE ELECTRICITY (BE)
  These bricks represent the total base electricity consumption resulting from the power demand that is continuous throughout the year.

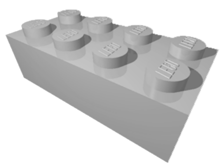
- PEAK ELECTRICITY (PE)
  These bricks cover the part of the electricity demand that only takes place during part of the day. PE is that part of the consumption that follows our activities: When we drive in a train, when we cook on an electric stove or when we watch TV.



The number of bricks is proportional to the areas on the graph above. Less variation in the demand curve results in more base electricity and less peak electricity bricks needed.



Base electricity consumption



Peak electricity consumption

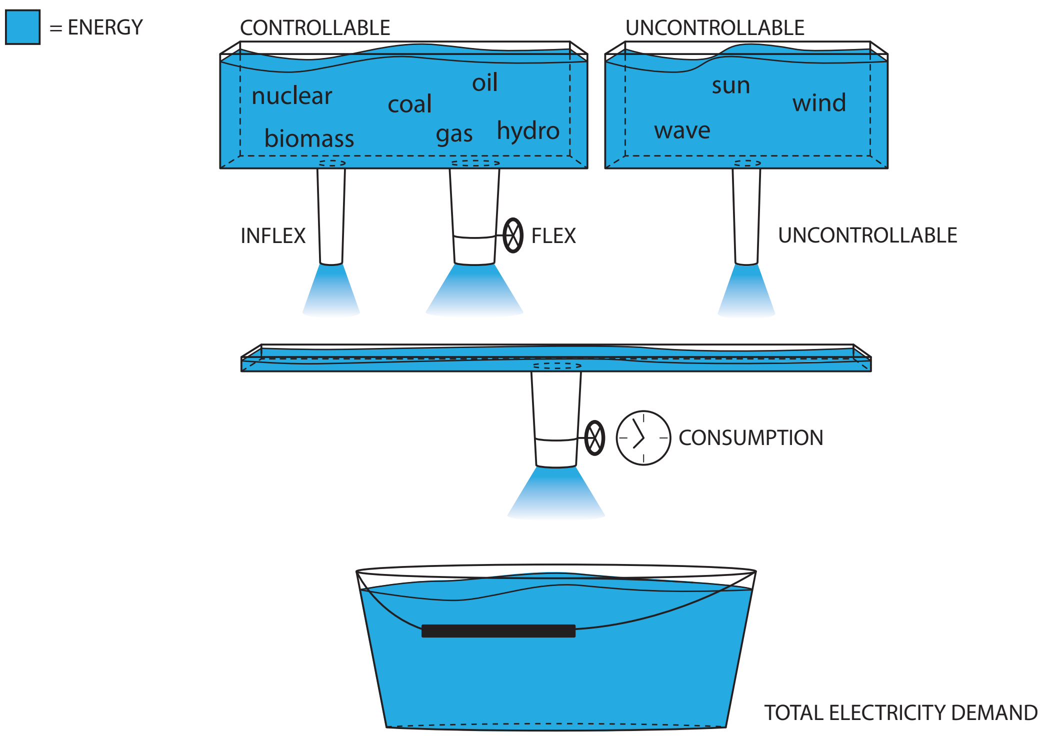
KEEPING THE POWER BALANCE

We can't easily store electricity, so it needs to be produced and delivered exactly when it is needed. That is the job of the electric power systems. This power system, on the one hand, enables us to take energy from the wind or sun and to use it right away, and it is therefore very important for integrating renewable energy into the system. On the other hand, this makes the electricity part of the energy system a bit more complicated. Going by the same analogy as in the beginning, we can explain this by imagining electricity as water that flows through pipes.

A USEFUL ANALOGY: WATER THROUGH PIPES INTO A BUCKET

A good way to conceptualize an electricity system is as sketched in the drawing below. On top we have the primary energy resources, which can be split in two: controllable and uncontrollable. How much and how fast water flows from the reservoir on the left (the controllable resources) is determined by the size of the two tubes coming from it. The flow through the left tube cannot be regulated, whereas the flow through the right tube can be adjusted by turning the knob on the valve. There is no knob to control the flow from the reservoir on the right (the uncontrollable resources).

Now again, think of energy as the amount of water, and power as the flow. The total flow (or power output) through the right tube from the left box depends on how much you open the valve. The water coming from the three tubes run into a shallow reservoir. A tube runs from this reservoir and the flow through this tube is the electricity demand. The tube has a valve which is controlled by a clock. We cannot influence how the valve adjusts during the day. Electricity demand must always be met, so water must constantly flow through the bottom tube into the large bucket at the bottom. However, if the flow from the above three tubes exceeds the flow of the lower tube the shallow reservoir will overflow. This corresponds to too much power being produced. The shallow reservoir being emptied corresponds to too little power being produced. In the real world, both would result in a system collapse resulting in a complete blackout with no power for anyone for several hours or days! At the end of the year, the amount of water in the bucket is annual consumption.



The challenge of making sure the tiny reservoir never overflows or becomes emptied is handled by adjusting the valve on the right tube from the left box throughout the year. When designing and operating the energy system, this valve must always be set such that the flow from the two boxes on top matches the flow through the bottom tube. In order to be able to do this, the system must be constructed such that:

1. The maximum flow through the tubes coming from the left must at least match the maximum flow through the bottom tube. This is to provide sufficient flow when the flow through the bottom tube is the largest and the flow from the right box is zero (these two events could happen at the same time).

2. The maximum flow from the right box plus the flow through the left tube from the left box is no larger than the minimum flow through the bottom tube. Otherwise the shallow reservoir will overflow.

Satisfying the above two constraints is a matter of sizing the tubes appropriately and making sure the valve is flexible enough. The size of the tubes corresponds to the term capacity (number of power plants), and is dependent on which power plants make up your electricity system.

PRODUCTION MUST FOLLOW CONSUMPTION

As touched upon in the analogy, there are two important limitations on a power system. Firstly, because of the demand profile, it is important to ensure that maximum demand can be met (peak demand). Secondly, but just as important, it needs to be ensured that no more electricity is produced than can be consumed (minimum demand). In terms of the analogy this is to avoid emptying or overflowing the tiny reservoir.

Adding uncontrollable plants to the system is not without problems. Uncontrollable plants produce electricity irrespective of whether electricity is needed.

Going back to the analogy, increasing the size of the tube from the right box will make the challenge of keeping the balance even harder for two reasons. Firstly, we cannot count on power from the uncontrollable capacity when we need it (risk of the reservoir becoming depleted). Secondly, when the uncontrollable output is the largest, or changes rapidly, the risk of overflow in the shallow reservoir increases.

FLEXIBLE AND INFLEXIBLE CAPACITY

Inflexible capacity is power plants that are operated continuously all hours of the year (the left tube with no valve). Flexible capacity is the power plants whose output is regulated to keep the power balance of the system with fluctuating demand and uncontrollable production. This is the right tube coming from the left box with a valve in the analogy. As the uncontrollable output increases, flexibility becomes more and more important. Flexible technologies like gas turbines can change their power output very fast, whereas inflexible technologies like nuclear power cannot. Adjusting the power output of a nuclear plant takes several hours. That is why wind energy is difficult to integrate into an energy system with a lot of nuclear power, for example. Usually an energy system is built such that some inflexible plants are operated all the time (base load plants) and some flexible plants operate only through part of the day (peak load plants). Adding uncontrollable capacity will require more flexible plants.

THE ELECTRICITY PRODUCTION TOWER

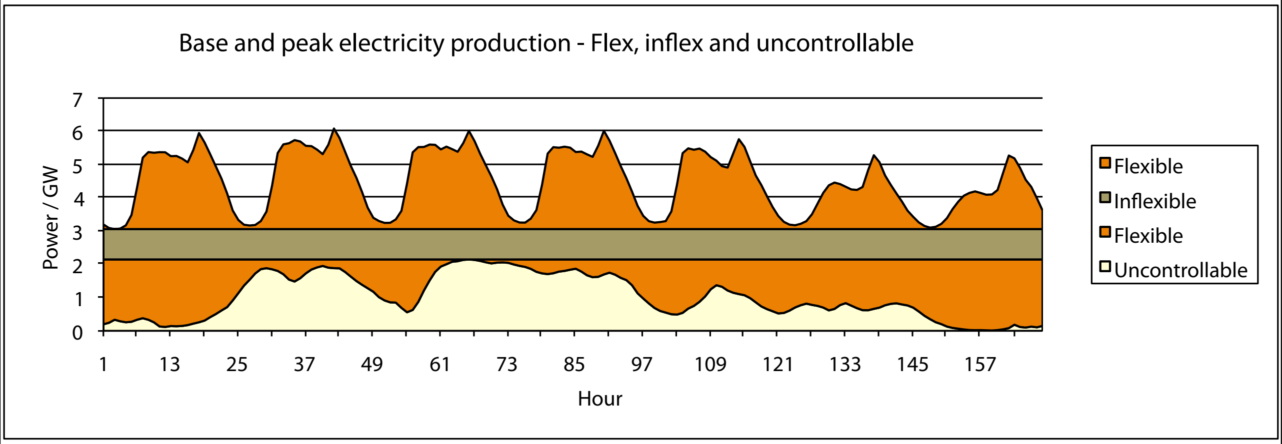
When constructing the electricity *production* tower both base electricity and peak electricity demand need to be met.

The **peak electricity target** can only be met by *flexible* technologies.
The **base electricity target** can be met with:

1. Inflexible power plants *or*

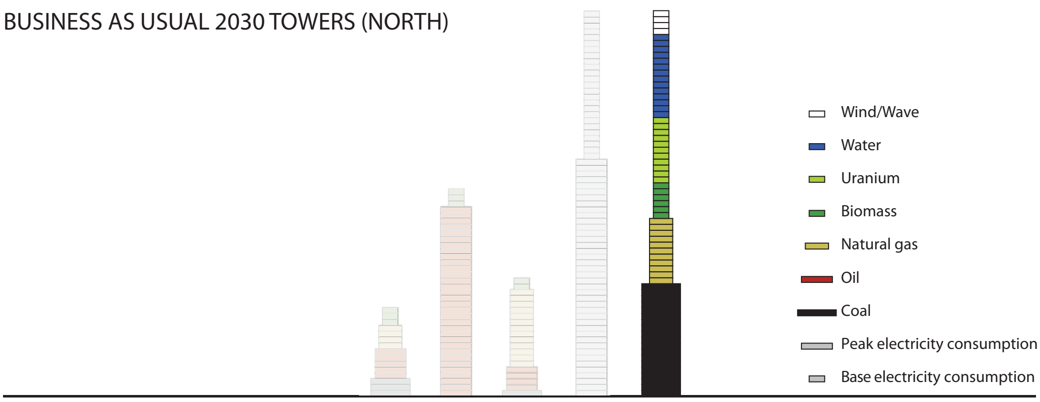
2. Uncontrollable *and* Flexible production.
   Each uncontrollable electricity production brick must be put with a flexible electricity production brick. This corresponds to the flexible technology taking over when the uncontrollable source is not producing; thus producing a stable electricity output.

In the figure below the entire peak electricity demand is covered by flexible production, whereas inflexible production covers about 1/3 of base electricity demand. The remaining 2/3 is covered by half uncontrollable and half flexible production.



ELECTRICITY PRODUCTION LEGO® BRICKS

Each brick represents the fuel input needed to produce 17.5 TWh of electricity *and* the capacity, i.e. the power plants that need to be built. For inflexible plants that are run continuously 2 GW of capacity is needed to produce 17.5 TWh per year. For flexible production (which is only run half the time), twice as many power plants (4 GW) are needed to convert the same amount of fuel. Uncontrollable production bricks contain the capacity needed to produce 17.5 TWh per year (this is technology specific).



CAPACITY CARDS

Electricity is produced or generated from other forms of energy. The capacity cards show which technologies can be used to generate electricity. They specify the *electricity production bricks* used to construct the *Electricity Production Tower.*

The technologies are classified in controllable (*flexible / inflexible*) and *uncontrollable* technologies:

CONTROLLABLE CAPACITY CARDS (E.G. GAS TURBINES):

Gas turbines

Gas turbines can be build at a low capital cost. However, the natural gas is expensive to buy and is by and large imported from Russia.

FLEXIBLE

900 MEUR per brick

INFLEXIBLE

800 MEUR per brick.

These power plants have two options, they can be built as *flexible* capacity or *inflexible* capacity. The two options have different costs.

For *inflexible* capacity - running all year around - the cost is given as the sum of the cost of *building the power plant capacity and the fuel cost.*

Flexible plants are assumed to only be operated half the time. Therefore, twice as many power plants are needed to generate the same amount of electricity per year. This results in the cost of flexible capacity to be *two times the power plant capacity cost + fuel costs.*

UNCONTROLLABLE CAPACITY CARDS (E.G. WIND POWER):

Wind Power

Windpower is only as reliable as the wind. Thus there is an inherent need for other power plants which can be swicthed on or off depending on whether the wind blows.

Uncontrollable

800 MEUR per brick.

On these cards you will find the price of adding uncontrollable capacity equivalent to producing one brick of electricity per year.

Remember that uncontrollable capacity may *only* be used to cover base electricity demand and *only* if being backed up by flexible capacity.

SUMMARY

ENERGY

FUEL LEGO® BRICKS (P. 7)
Each LEGO® brick of coal, oil, natural gas and biomass represents 125 Peta Joules of primary energy, which can be used in all fuel towers.

> **Pollution:** The width of the bricks that represent fossil fuels (*coal, oil, natural gas*) accounts for the CO_2 emission from this brick. All other bricks (including CCS Coal) are assumed not to result in CO_2 emissions. CO_2 emissions are the only type of pollution accounted for in the game. In your discussions, please take also other types of pollution into consideration: land use, visual impact, local air pollution etc.
>
> **Primary Energy:** The color of the bricks represents the primary energy resource. That is, the energy resource found in nature (e.g. coal, uranium, wind). It needs to be converted into a useful form of energy like *electricity, heat* or *motion*.

ELECTRICITY CONSUMPTION LEGO® BRICKS (P. 13)
We distinguish between two types of electricity consumption: Base Electricity (BE) and Peak Electricity (PE). PE is that part of the consumption that follows our activities. BE is the part of electricity that is consumed also at night when we sleep.

Each brick represents an electric output of 63 Peta Joules (or 17.5 TWh). This is comparable to the fossil fuel and biomass bricks it is assumed these could be converted to electricity at 50 % efficiency.

> Electricity as we use it is not found in nature but needs to be produced from primary energy resources in an electricity system. The production of electricity is taken care of in the next part of the game → *Electricity production tower.*

ENERGY SERVICE (P. 8)
A benefit we derive from an activity using energy. Energy services could be clean clothes, light for reading, comfortable indoor temperature, transportation.

ENERGY EFFICIENCY (P. 8)
Energy efficiency of a process is defined as the ratio of useful energy output or service to the energy input.

FUEL TOWERS (P. 10)
The *fuel LEGO® bricks* are stacked in towers to represent how much fuel energy is being used in a sector. There are three fuel sectors:

> **Heat:** This tower shows the fuels used to heat our buildings and to provide hot water. This could be charcoal, oil, gas or wood burned in a stove. *Electricity used for heat is not included.*
>
> **Transportation:** Cars, trucks, trains, airplanes, and ships require energy. The transportation tower shows fuel energy input to all modes of transportation. This is primarily oil for gasoline and diesel. Biofuels are represented as biomass bricks. *Electricity used for transportation is not included.*

Industry: Primary energy as fuels burned to produce high temperatures for various processes in industry. For example coal burned to heat cement or natural gas used to preheat metals for processing. *Electricity used in the industry is not included.*

ELECTRICITY CONSUMPTION TOWER (P. 10)
The electricity consumption tower covers electricity use for all purposes. It is composed of a base and a peak electricity part. Both parts stacked on top of each other represent the total amount of electricity that needs to be generated (→*Electricity Production Tower*). The top part (peak electricity) needs to be generated from more expensive flexible power plants than the less expensive bottom-part (base electricity).

CHANGE CARDS (P. 11)
Each Change card describes a Change which would have an effect on your energy system. On each card you will find a short description of the Change, the cost of implementing the change and description on how it affects your towers. These cards can be played if everyone in the group agrees to do so.

Changes may affect:

§ The number of bricks in the *tower representing the sector* to which the change applies.
§ The number and kinds of bricks in the *electricity consumption* tower.
§ Your *balance*, since most changes cost money or involves fuel savings.
§ Other effects not included in Changing the Game (e.g. local pollution, loss of convenience, etc.)

POWER

CAPACITY CARDS (P. 17)
Electricity is produced or generated from other forms of energy. The Capacity cards show which technologies can be used to generate electricity. They are used to construct the *Electricity Production Tower*. The technologies are classified in controllable (*flexible / inflexible*) and *uncontrollable* technologies. Which type the technology provides is stated on the capacity card.

ELECTRICITY PRODUCTION LEGO® BRICKS (P. 7)
Each brick represents the fuel input needed to produce 17.5 TWh of electricity *and* the capacity, i.e. the power plants that need to be built.

For inflexible plants that are run continuously 2 GW of capacity is needed to produce 17.5 TWh per year. For flexible production (which is only run half the time), twice as many power plants (4 GW) are needed to convert the same amount of fuel. Uncontrollable production bricks contain the capacity needed to produce 17.5 TWh per year (this is technology specific).

ELECTRICITY PRODUCTION TOWER (P. 16)
This tower represents all the power plants, wind farms, etc. needed to produce the power output shown in the electricity tower *and* the energy resources used for power generation.

The production has to meet the consumption, therefore this tower must be as high as the *Electricity Consumption Tower,* and is also split in two parts. Some technologies only fit in the bottom part. Some only in the top part.