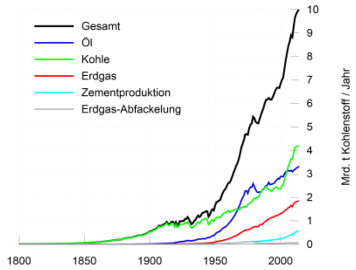
The Turbo-CO_2-Capture Process (TCP)

The key elements of the energy turnaround are the expansion of regenerative energy and the increase of energy efficiency that guides to a reduction of the emission of greenhouse gas. The percentage of regenerative energy in Germany increases from 36% in 2017 to 37,8% in 2018. With this slow increase Germany reaches in 2053 a 100% energy production by regenerative energy, whereby the problems of energy storage and interception of peak loads remain unsolved. "In medium and long-term an energy production by fossil fuels can't be waived. Cole fired power plants will be the main basis for energy production." The German department of environment, nature protection and nuclear safety (BMU) comes to that conclusion. During the period to come to a climate neutral or better climate positive energy production it is necessary to produce energy with the existing power plants. But it is impossible to go on in the meantime with increasing the climate catastrophe by emitting CO_2 in the atmosphere. The TCP-process extracts CO_2 from waste gas that could be used in industrial processes or stored in the interior of the earth, for instance in exhausted gas reservoirs to prevent an increasing the CO_2 concentration in the atmosphere. An industrial usage of CO_2 as a valuable raw material makes good progress, but the quantity produced in power plants exceeds this portion by magnitudes.



Picture 1 CO_2 emission worldwide

The common, worldwide, legal binding goal of the United Nations framework convention on climate change is the reduction of CO_2 respectively to the emission of 2009 of

- 40% until 2020
- 55% until 2030
- 70% until 2040
- climate neutral until 2050

The German Federal Environmental Agency discloses that these goals will be missed in 2020 and also 2030. For getting closer to the decided CO_2 reduction values the emission in the atmosphere has to be replaced. "Without an alternative, worldwide CO_2 storage in the interior of the earth all agreed climate goals will be missed." That is a result of the international scientists team around Felix Creutzig from Mercator Research Institute on Global Commons and Climate Change.

Biomass (algae, plants etc.) need for their growth Carbon. They extract from the atmosphere CO_2 and separate C and O_2 in the photosynthesis process. Carbon is integrated in the plants structure and O_2 is emitted to the atmosphere. Of course this process would be ideal for CO_2 reduction in the atmosphere, because no external energy is necessary for this process. In average a forest can transfer 4 t CO_2 per year. A 400MW GaS (gas and steam)-power plant emits 1.2 Mio. t CO_2 per year (a 400MW brown coal plant emits 4 Mio. t CO_2 per year). For compensation of only one of these power plants you need 25% of all forest area of Germany. The power consumption of Germany is only 2.4% of the worldwide power consumption. These numbers show that CO_2 compensation by photosynthesis is far too small to reduce CO_2 concentration in the atmosphere.

Only a direct CO_2 capture from waste gas and either storage in the interior of the earth would lead to the desired results (CCS-process). A CCS process includes:

1. capturing of CO_2 from waste gas,
2. transport of CO_2 to a appropriate storage place and
3. storage.

For economical and ecological reasons this process has to be done with a minimum of energy. The Turbo-CO_2-Capture Process (TCP) complies this demand at best, because it needs 50-70% less energy in comparison to all other CCS-processes.

Power production connected with a CCS-process results that

- power plants with fossil fuel will be climate neutral and
- power plant with regenerative fuel will be climate positive, cause the used biomass extracts CO_2 from atmosphere during their growth process and the CO_2 concentration in the atmosphere decrease.

The climate warming process by energy production with biomass-fuel combined with a CCS-process will be inversed!

All CCS-processes need energy, which reduce the efficiency of the power plant. In the following chapters we will take a 400MW GaS-plant and a 400MW brown coal-plant (BOA-plant) as examples for an economic examination. As already mentioned these power plants emits 1.2 (GaS) and 3.3 (BOA) Mio. t CO_2 per year. The average energy sales price 2018 in Germany was 45€ per 1 MWh. The production cost of a GaS-power-plant was 42€, of a BOA-power-plant 29€ resulting from the different fuel prices. This difference in production prices results the fact that 90% of all fossil-power-plants are brown-coal-power-plants. The new upraised CO_2 tax in Germany starts with 10€/t CO_2 in 2021 and increases to 35€/t CO_2 in 2025. The total sales of a 400MW –power-plant is 158Mio. € (2018). The CO_2 tax increases the production costs by 42 Mio.€ (GaS = 26%) respectively 115 Mio. € (BOA = 73%) per year. This would increase the production costs to 54 €/MWh (GaS) and 62€/MWh (BOA). The existing number of GaS-power-plants is far too small to substitute the existing coal-power-plants, whose production costs will be doubled. With the same profit as before for the power-plants the prices for energy would be doubled in 2025 too, which is an economical problem for the end users.

Figures 400MW Electrical Power	GaS	Brown Coal BOA
Fuel Consumption	671 MW	1.001 MW
Electrical Efficiency	60%	40%
Electrical Power	403 MW	400 MW
CO_2 Emission	0,34 t/MWh	0,94 t/MWh
Sales Price Without CCS	45 €/MWh	45 €/MWh
Production Price Without CCS	42 €/MWh	29 €/MWh
CO_2 Tax		
CO_2Tax 10 €/t CO_2 Starting from 2021	11.913.600 €	32.937.600 €
CO_2Tax 35 €/t CO_2 Starting from 2025	41.697.600 €	115.281.600 €

Table 1 Figures of a 400 MW power plant

CO_2 Capture in Waste Gas

Necessary requirement to prevent the CO_2 tax and the implemented increase of energy costs is the implementation of a CCS process. Therefore it is necessary to identify and operate interior of the earth CO_2-storage places immediately! At this point the legislative authority has to create the necessary legislative conditions to enable the self-postulated reduction of CO_2 emission.

Currently there are three different CCS-processes tested.

1. *Post-Combustion-Capture-Process*
   The most tested process is the chemical washing process. After dust precipitation, soot separation and desulphurization a chemical substance is sprayed in ultra-fine drop shape in the remaining waste gas. 90 % of the CO_2 sticks to these drops and will be separated from the process. Afterwards they are separated thermally. CO_2 will be removed and the chemical substance is ready for a new capture process.
   During the test in a BOA power plant the chemical washing the following problems cropped up
   - Decomposition of the chemical substances by Oxygen, Sulphur Dioxide, Nitrogen or dust
   - Emission of parts of the chemical or other harmful substances
   - A very power consumptive thermal dissolving process

   These problems prevent an economical success of this CCS-process.
2. *Pre-Combustion-Capture-Process*
   The fuel will be gasified and the fuel gas is afterwards transformed with different chemical reactions to Hydrogen. Then CO_2 is extracted with the same chemical washing process and the same problems explained already in the post combustion process description. Afterwards Hydrogen is burned in a gas turbine. The waste gas consists mostly of Water and Nitrogen and is directly emitted to the atmosphere.
3. *Oxy-Fuel-Process*
   The fuel is burned with pure Oxygen. In this case the waste gas consists mostly of water and CO_2, but also of Sulphur compounds and parts of Nitrogen. The water can be simply extracted by cooling and the remaining waste gas consists by 90% of CO_2.
   For this process you need an air separation plant to produce pure Oxygen.

The TCP-process is also a post combustion CCS-process. After dust precipitation and soot separation the waste gas is compressed and cooled to the liquefaction of CO_2. The base technology of this process is known since more than 100 years and used on an industrial scale in steam reforming processes for Hydrogen production. Undisputed this process has the following advantages.

- 100% CO_2 is captured single origin
- physically separated without additional chemical substances and related problems
- Sulphur compounds and water are also separated by 100%
- so the remaining waste gas in this process is only Nitrogen

The literature describes this process as too power consumptive and therefore not useful. Exactly here instates the TCP-process. Our patent cuts down the necessary energy costs by 50-70% in respect to the chemical washing.

Only a post-combustion-processes can be used to separate CO_2 from existing power plants. In the following chapters we only compare the post combustion processes, because only these processes could reduce immediately the CO_2 emission of the existing power plants and contribute to the goals of CO_2 reduction in the atmosphere.

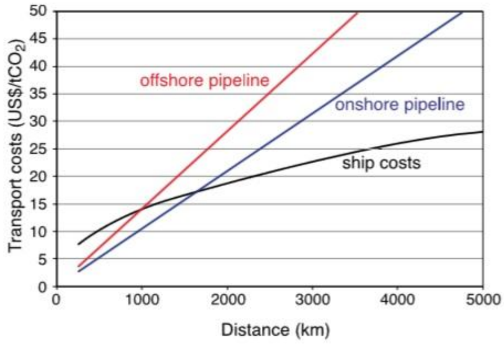
CO_2 Capture Energy Consumption	GaS	Brown-Coal-BOA
Chemical Washing	41 MW	63 MW
Turbo-CO_2-Capture	**21 MW**	**59 MW**

Table 2 Energy Consumption for CO_2 Capturing

The capturing process requires the energy listed in Table 2. The energy consumption of the TCP-process is nearly 10% less for a BOA-plant and only the half for a GaS-plant. The differences in energy consumption for both 400MW example-plants results from the quantity waste gas.

CO_2 Transport to Interior of the Earth Storage Places

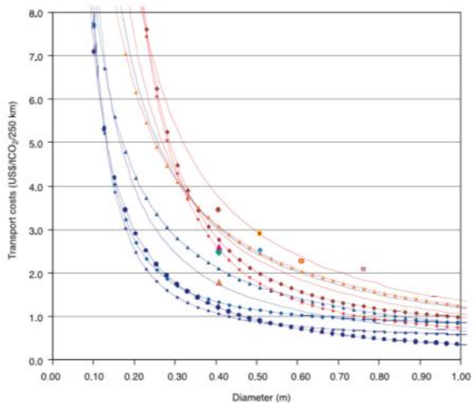
The TCP-process captures CO2 in liquid form and 7 bar pressure. Then the liquid is compressed by a compressing pump to 100 bar, which is the necessary pressure to store CO2 in depth more than 800 m. Afterwards CO2 will be transported via pipelines to a suitable storage place. During transport at ambient temperature the CO_2 warms up and transits in his gaseous supercritical physical state.



Picture 2 transport costs / distance

As shown in picture 2 the transport via pipelines is in most cases the most economical transport method. Only distances more than 1500 km between power plant and storage place makes a transport by ships – if possible at all – less expensive. For transportation CO_2 has to be compressed or solidified. CO_2 captured by a TCP-process can be solidified by a simple expansion to dry ice, so a transport via pipeline or ship is both possible without any additional energy consumption.

In one 400MW power-plant 36 (GaS) or 105 (BOA) kg CO_2/sec has to be transported. A transport under atmosphere pressure and temperature let to a pipeline diameter of 3.5 m, which would make the production costs for the pipeline exorbitant expensive. CO_2 under 100 bar pressure needs only a pipeline diameter of 0.15 m. As shown in picture 3 we see that the optimum between diameter and transportation costs is 0.3 m. In this case the transportation costs per 250 km is 1 €.



Picture 3 Transport Costs / Pipeline diameter

CO_2 is compressed in the TCP-process in liquid form. Therefore the necessary energy

CO_2 Transport Compression (100 bar) Energy Consumption	GaS	Brown-Coal-BOA
Chemical Washing	17 MW	46 MW
Turbo-CO_2-Abscheidung	**0,09 MW**	**0,26 MW**

Table 3 energy consumption CO_2 for pipeline transport

consumption is maximum 0.5% respectively to the chemical washing where the compressing has to be done in a gaseous physical state.

CO_2 Storage in Interior of the Earth Deposits

CO_2 can be stored in

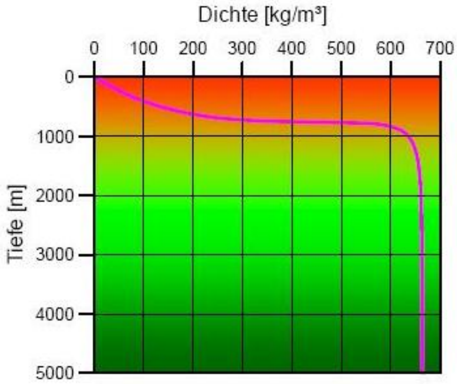
- depleted hydrocarbon fields

- onshore as well as offshore in saline aquifer and
- submarine areas

CO_2 is stored in industrial scale in front of the Norway coast since 1996. Also in the USA CO_2 storage deposits are in use. In Germany the suitable deposits are explored but not jet in use due to the fact of selfishly legal actions by residents. The Federal Institute for Earth Sience and Natural Resources (BGR) announces that the storage of CO_2 in carefully explored suitable deposits is only of low risk. At least depleted hydrocarbon fields are ideal deposits, because they demonstrable stored gas or oil over millions of years. At this point the legislative authority has to create the necessary legislative conditions to enable the self-postulated reduction of CO_2 emission. As more time goes by until starting point of CO_2 storage as more we increase the climate catastrophe.

As shown in picture 4 the optimized storage depth is below 800 m, where a compact as possible storage for optimized usage of the existing storage capacity starts. The CO_2 pressure has to be more than 80 bars respectively.

Practical experience, knowhow and equipment for the grouting in geological formations are status of today in natural gas production and can be transmitted to the CO_2 storage one by one.



Picture 4 CO_2 Density / Storage Depth

There is no valid cost calculation for CO_2 storage in the interior of the earth. Therefore we assume 2€/t CO_2, which is the average of accessible cost calculations.

Feasibility Study of the CCS-processes

The complete CCS-processes require the total energy shown in table 4.

Total energy consumption CCS	GaS	Brown-Coal-BOA
Chemical Washing	58 MW	109 MW
Turbo-CO_2-Capture	21 MW	59 MW

Table 3 Total Energy for CO_2 Capture, Transport and Storage

The TCP-process needs roundabout 50% less energy than the chemical-washing-process. This energy consumption reduces the power of the two 400MW example-plants as shown in table 5. The efficiency of the GaS-plant is reduced by 4.4% from 60% to 57.4%. The brown-

Total Plant Power	GaS		Brown-Coal-BOA	
Without CCS-process	400 MW	Efficiency 60%	400 MW	Efficiency 40 %
With CCS-process	Power	Decrease	Power	Decrease
Chemical Washing	345 MW	13,7%	291 MW	27,2%
Turbo-CO_2-Capture	382 MW	4,4%	341 MW	14,7%

Table 4 Power Reduction of the 400MW Example-Plants by CCS process

coal-BOA-plant is reduced by 14.7% from 40% to 34.1%. So the basic energy supply with the existing power-plants including a Turbo CO_2 capturing and storage process would be secured. The loss of power could be covered by the reserve capacity of the plants.

Additionally to the direct cost for capturing and compression for all CCS processes comes costs transport and storage of 3€/t CO_2. This results the comparison with and without CCS process and CO_2 tax in table 6 in respect to the profit in 2019.

Feasability Study of a 400MW Power Plant	GaS	Brown-Coal-BOA
Compensation 2019	158 Mio. €	158 Mio. €
Additional Costs by CCS-process		
Chemical Washing	23 Mio. €	43 Mio. €
Turbo-CO_2-Capture	8 Mio. €	23 Mio. €
Production Cost 2019	147 Mio. €	102 Mio. €
Production Costs 2021 incl. CO_2 tax	159 Mio. €	135 Mio. €
Production Costs 2025 incl. CO_2 tax	189 Mio. €	217 Mio. €
Production Costs with CCS-Process		
Chemical Washing	170 Mio. €	144 Mio. €
Turbo-CO_2-Capture	155 Mio. €	125 Mio. €

Table 6 Feasability Study

With the TCP process the production costs increases from 147 Mio.€ (GaS in 2019) to 155 Mio.€ and from 102 Mio.€ (BOA 2019) to 125 Mio.€. This comparatively low increase of 10-20 % in production costs guarantees also a tolerable increase in prices for the end users. The TCP-process saves a power plant in 2025 taxes in the amount of 34 Mio.€ (GaS) and 92 Mio.€ (BOA) per year. Most important is the fact, that the CO_2 balance in the atmosphere is unchanged and the climate catastrophe is not increased by electrical power production by an existing power plant.

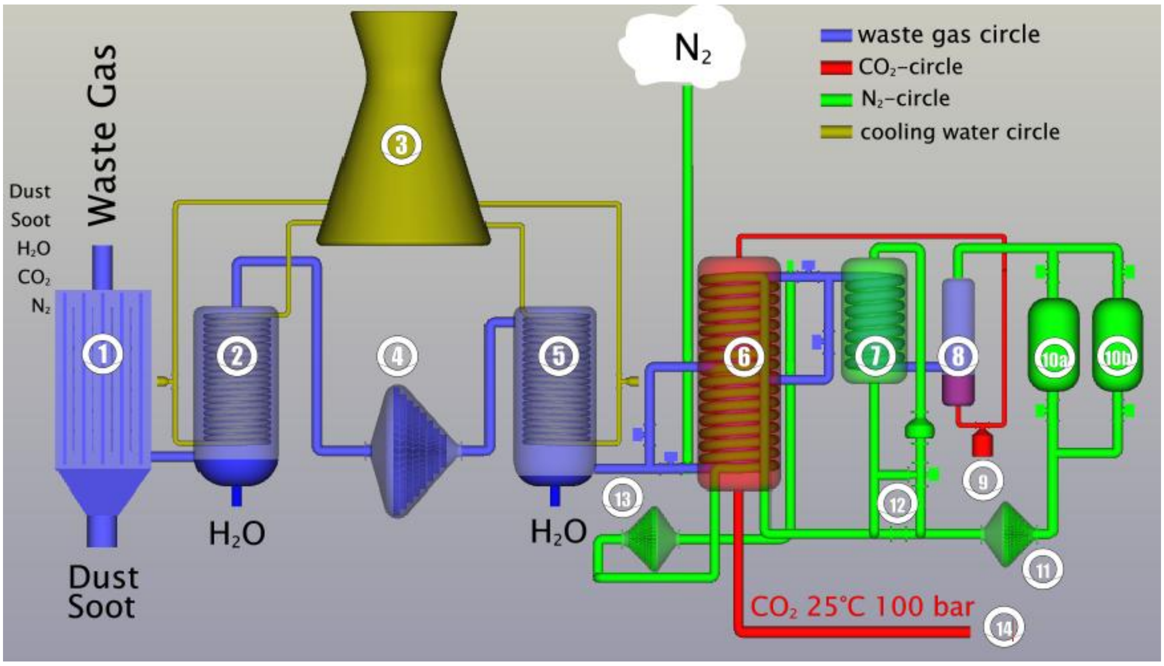
CO_2 capturing and storing with the TCP-process is 47-65% cheaper than the chemical-washing-process.

The TCP process is the superior method of CO_2 capturing and storing because

- extreme low reduction of the efficiency of a power-plant
- results basic energy supply is secured
- production prices increase only by 10-20%
- results moderate increase of the supply costs for the end users

The Turbo-CO_2-Process

The TCP-process for extracting CO_2 from waste gas from power plants, turbines, engines etc. consists of the following single steps:



Picture 5 Turbo-CO_2-Capturing Process

The waste gas is cleaned in the first cleaning stage from dust, soot and similar contaminations (1). Afterwards the waste gas, that typically has a temperature of 100°C to 150°C will be cooled to ambient temperature (2)(3), then it will be compressed by a Turbo-compressor to 7 bar (4) and once again cooled to ambient temperature (5)(3). The water in the waste gas will be mostly extracted in these two process steps. Also the Sulphur components, eventually contained in the waste gas will be captured in this process step. In the following step the waste gas will be cooled down to -45°C in a self cleaning heat exchanger (6). CO_2 condense at the temperature/pressure ratio 7bar/-45°C and is captured in the CO_2-condensor (7)(8). With an high pressure pump (9) it will be afterwards compressed in its fluent state to 100 bar. Then it flows through the self cleaning heat exchanger and will be warmed up to 25°C (6) and is ready for transportation to the storage deposit (14). The waste gas contains after the CO_2 capturing mostly N_2 with a small rest of CO_2, which will be extracted in the adsorbers (10a)(10b). The compressed cold N_2 will be used as a cold source for the CO_2 condensor (12) and the self cleaning heat exchanger (6). During the flow through of the different heat exchangers N_2 is warmed up and will be expanded with the expanding turbines (11)(13) and thereby cooled down again, while a bigger portion of the compressing energy from the turbo compressor (4) will be recovered. After the last expanding step (13) the N_2 is tight to ambient pressure and is used in the last process step for cooling and cleaning of the self cleaning heat exchanger (6) before it is released to the atmosphere.