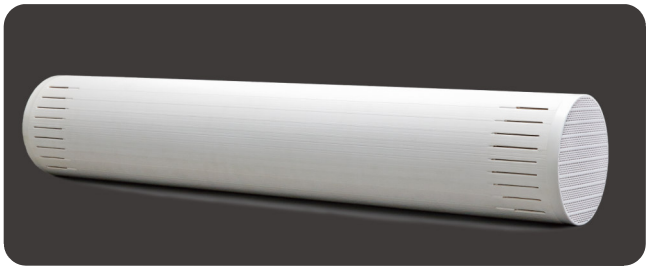
Sub-nano Ceramic Membranes

NGK EUROPE

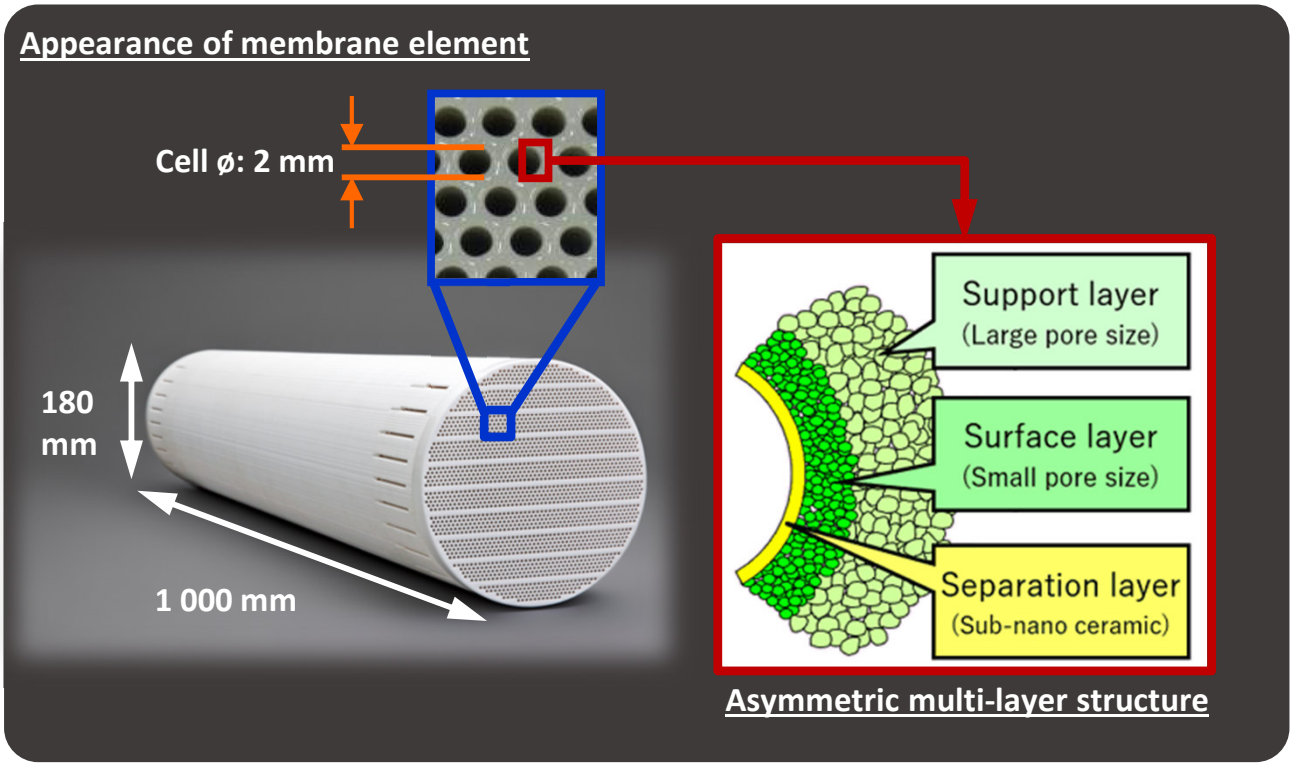
Surprising Ceramics.

Ceramic membrane for different separation tasks

The use of membranes in separation processes is gaining more and more interest as it needs less energy compared to classical separation methods, e.g. distillation or extraction.



NGK developed a ceramic membrane that targets **separation on a molecular level** of specific gases or liquids from gaseous or liquid mixtures. This is achieved by applying a zeolite with sub-nano (< 1 nm) diameter pores.



NGK's ceramic membrane consists of an extruded alumina body, with 1 000 mm length and 180 mm diameter, that features three layers inside about 1 600 channels:

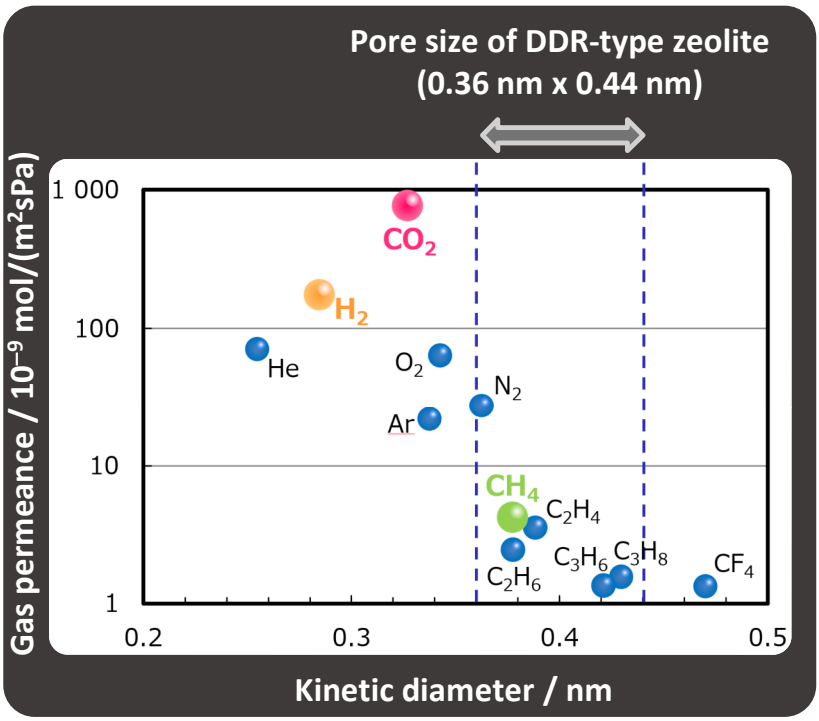
- Support layer with a larger pore size diameter
- Surface layer with a smaller pore size diameter
- Separation layer as a DDR-type zeolite with sub-nano pore size diameter

The zeolite has **uniform fine pores** and NGK's expertise and knowledge in ceramics handling allows an almost **defect free layer**, what is a key criteria for superior selectivity.

Another feature are slits on the sides that facilitate the molecule transport.

Sub-nano zeolite for molecular separation

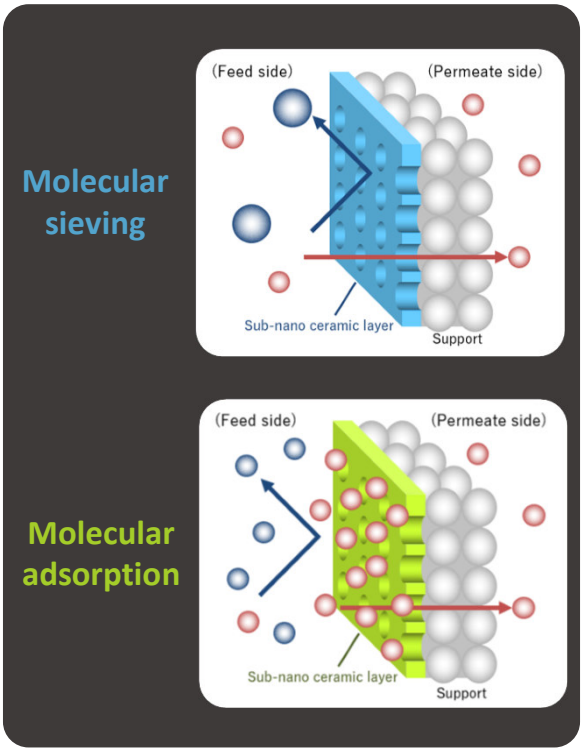
The separation layer can consist of crystalline zeolite but can also feature other materials with **uniform fine pores**. According to the target molecules the sub-nano ceramic layer can be chosen for good separation.



As an example, the DDR-type zeolite with its oval pores with the size of 0.36 nm x 0.44 nm can separate small molecules – like hydrogen or carbon dioxide – well from bigger molecules like hydrocarbons.

The **permeance** is an indicator for the ability of a molecule to pass through the separation layer and a high quotient of molecular permeances represents a **high separation factor or selectivity**.

Separation mechanism of this pressure driven process is based on **molecular sieving effect** on one hand, where molecules are separated by their size, and **molecular affinity** on the other hand, which is based on adsorption properties of molecules and membrane layer.

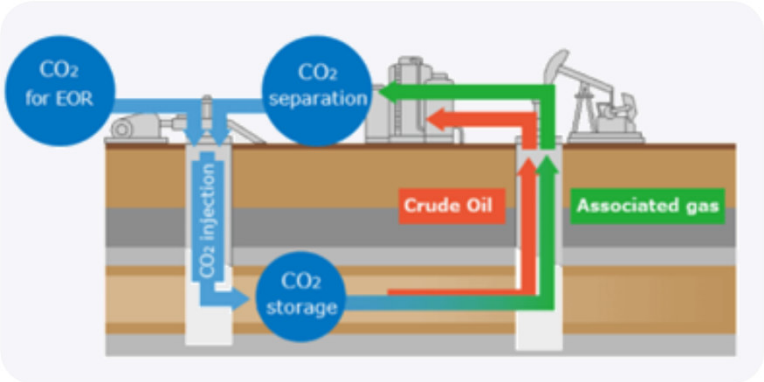


The most important features of the ceramic membrane are:

- ✓ High CO_2 permeability with high selectivity towards hydrocarbons
- ✓ High thermal resistance > 200 °C
- ✓ Pressure resistance up to 80 bar difference
- ✓ Low pressure loss
- ✓ High membrane surface area per module
- ✓ Compact design
- ✓ Low energy consumption ergo less CO_2 emissions

Selective CO_2 separation from hydrocarbons

NGK is performing field tests with a partner in the **enhanced oil recovery (EOR)** to separate the contained CO_2 from the hydrocarbons contained in the extracted stream.



Besides the effect of lowering the viscosity of the residual oil and thus facilitating the extraction a part of the injected CO_2 remains in the ground. This makes it possible to apply this method for carbon capture and storage (CCS).

The use of the ceramic membrane **under high pressure and CO_2 concentration** offers a cost-effective method to reuse the extracted CO_2 even under elevated temperatures.

Another application for NGK‘s ceramic membrane is the use in **biogas upgrading** where the contained CO_2 in the raw biogas is separated from CH_4 to obtain the so called **biomethane**, a renewable source of energy.

A two-stage system will enable the user to get a high-purity CH_4 stream as well as a high purity carbon dioxide as product.

Besides the usual biogas from anaerobic digester the ceramic membrane technology can also be applied to purify **landfill biogas**. Here, a higher nitrogen (N_2) content is present that causes problems to other membrane systems. The sub-nano zeolite can separate N_2 from the CH_4 as well, enhancing the value of the latter.

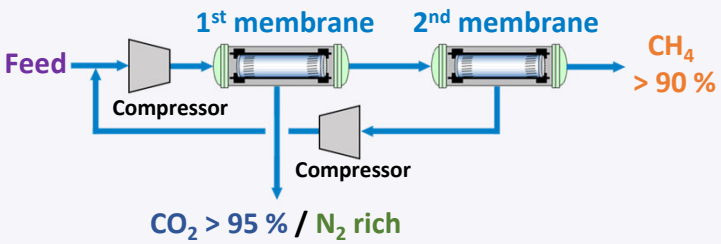
Digester biogas

Landfill biogas

Feed gas composition

50 % CH_4 50 % CO_2	45 % CH_4 45 % CO_2 10 % N_2

Two-stage process

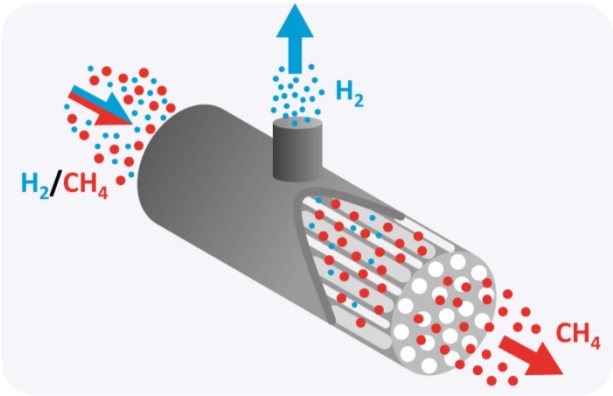


Efficient hydrogen separation from gas storage or pipe

To reach climate goals many efforts are needed, one pillar for greenhouse gas emissions reduction is the use of clean hydrogen. A big question will be how the produced hydrogen is stored and transported safely and in high amounts.

Here the **underground storage of hydrogen** under high-pressure conditions is in the focus. Often various other gases – mainly methane or other hydrocarbons – are contained in the extracted gas after the storage.

As for pipeline transport in some cases **blending** of H_2 into natural gas pipeline is considered.



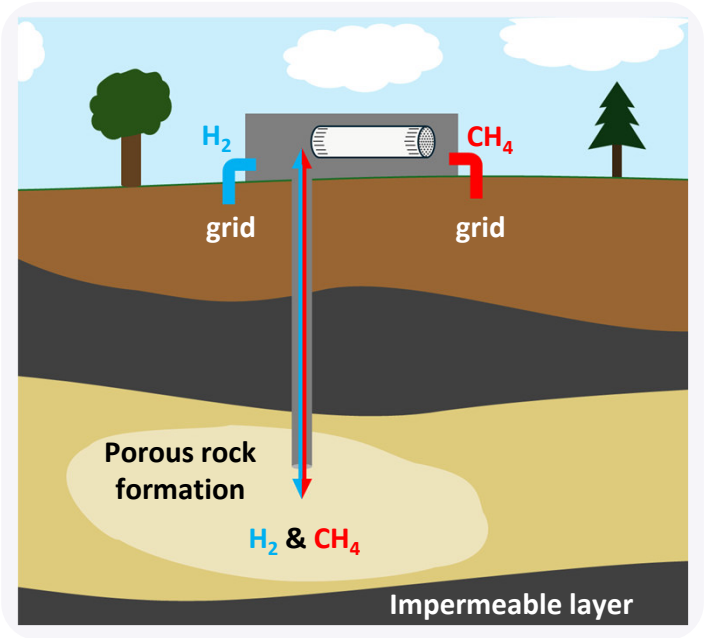
To reach the targeted high purity of the extracted hydrogen an efficient separation of hydrogen from the impurities is necessary. The same holds true for deblending at the end of the pipeline.

Ceramic separation membranes offer a **high-pressure tolerance**, eliminating the need for pressure reduction. In addition, the **high selectivity for hydrogen towards hydrocarbons** contributes to an efficient process.

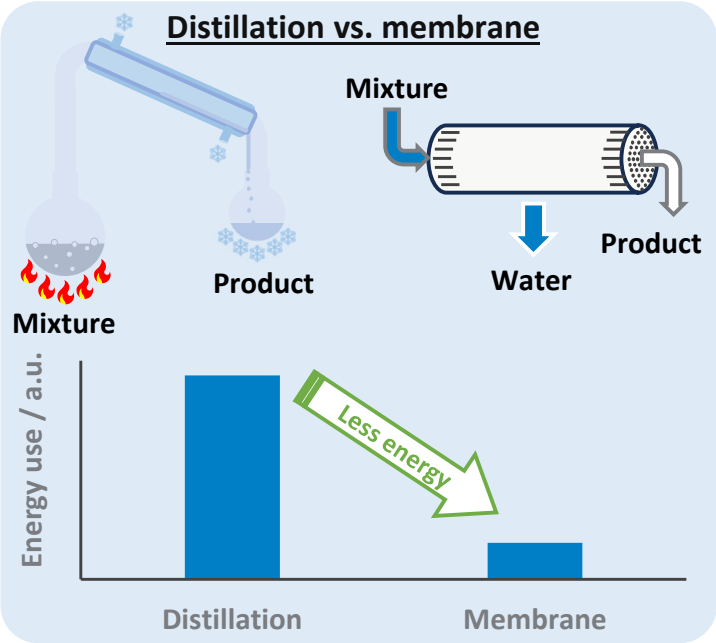
There are several underground storage types:

- Aquifers: Here bacteria can produce different unwanted contaminants from the hydrogen
- Salt caverns: Microbiological activity in the brine can cause pollutions
- Depleted oil/gas reservoirs: In these porous rock formations often impurities of left over hydrocarbons are contained

Only in the latter case, natural gas is used as **cushion gas** for the stored hydrogen which requires a **separation of H_2 and CH_4** that can be achieved by NGK‘s ceramic membrane during extraction process.



Energy efficient water removal from organic liquids



Removing water from organic liquids is an important process in chemical industry that is requiring enormous amounts of energy in traditional methods like distillation or the use of chemical drying agents.

Employing NGK's ceramic membrane can help to **reduce the energy consumption** and material usage drastically here. Thus, it represents an efficient way of product purification in this sector. The process itself is pressure driven like all membrane processes.

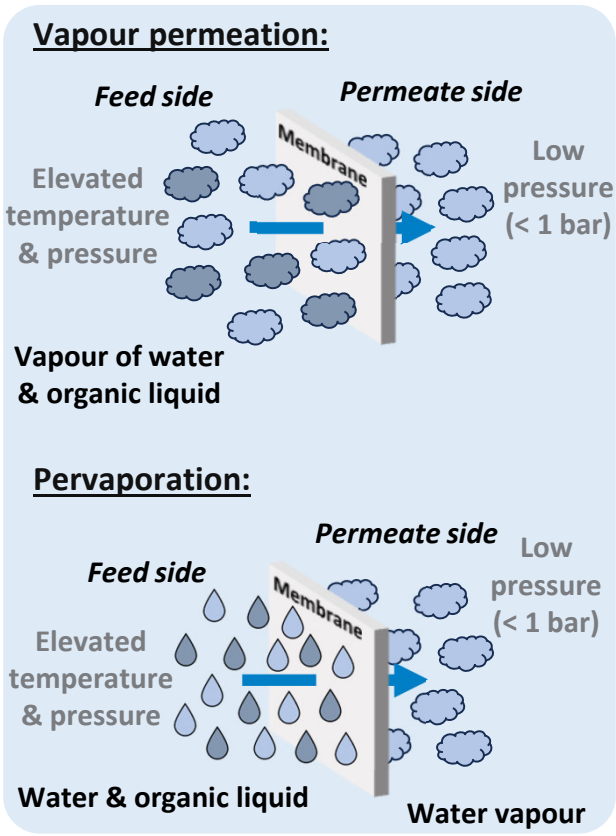
The two methods applied for membrane dehydration are:

- **Vapour permeation (VP)**: Separation occurs via the gas phase after evaporation of the liquid mixture
- **Pervaporation (PV)**: The heated feed flows in liquid form through the membrane and is separated there

On the permeate side a low pressure of a few hundred millibar is applied that acts as the driving force for the water to permeate. The separated water as well as the product in the retentate can be obtained almost in pure form.

NGK's ceramic membrane can be used to dehydrate alcohols, ketones, ethers, esters, aromatics and organic acids.

A complete replacement of a distillation unit can be targeted but a **hybrid process** with combined distillation tower and membrane offers energy savings, too.

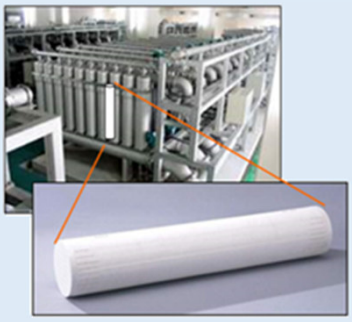


Liquid and solid

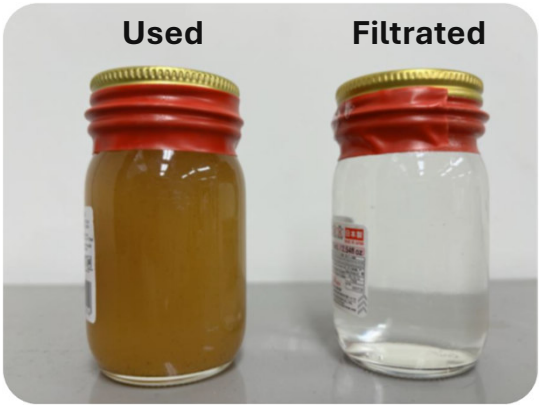
Efficient water treatment for oil & gas

Ceramic membrane-based **produced water treatment** (CMPWT) provides advanced filtration for oil and gas operation. CMPWT supports applications including produced water reuse, pipeline cleaning, re-injection, fracturing water desalination, irrigation, and discharge.

- ✓ Mechanical robustness and high structural integrity ensure **long-lasting performance**
- ✓ Hydrophilic nature and high permeability enable **high water flux and efficient filtration**
- ✓ Very **sharp pore size distribution** removes at least 98 % of particles 0.2 µm or larger
- ✓ **Produces high-quality water** that meets injection criteria, reducing reservoir plugging risk
- ✓ **Lowers investment and operational costs** by simplifying treatment processes and reducing footprint
- ✓ Simple system design leads to **less maintenance and downtime**



Ceramic membrane

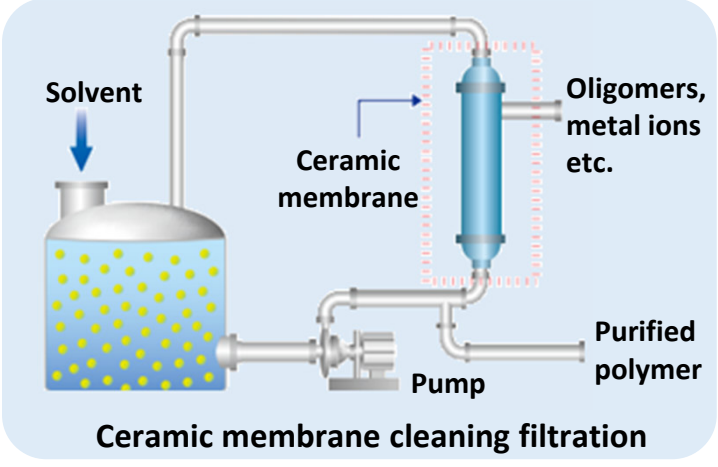


OSN (Organic solvent nanofiltration)

Product purification with ceramic membranes

Ceramic membrane systems are ideal in the use for **OSN**, for removing by-products, concentrating products, cleaning during crystallization and in-situ solvent exchange.

Application fields range from **chemical** over **natural** to **pharmaceutical products**.



Ceramic membrane cleaning filtration

Advantages of ceramic membranes in OSN:

- ✓ High resistance to organic solvents
- ✓ High nano-level separation performance
- ✓ High temperature resistance

You want to know how our membrane can help you in your process?

Following information is necessary to give you feedback on this:

1. **Process gas/liquid composition besides main components**

2. **How do representative process parameters look like?**

   - Pressure
   - Temperature
   - Flow rate

3. **Are there target values for purity and recovery rates?**

- **NGK can perform simulations to support initial assessment**
- **Small membranes for test purpose can be offered**
- **Housings are available as well**

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