The better barrier for fuel containment
Introducing EVAL Europe

Kuraray and EVAL Europe

Kuraray Co., Ltd. has long been a leader in high gas barrier technology and development. The company is the first and foremost producer of EVOH (ethylene vinyl-alcohol copolymer resins) under the name EVAL™ and the manufacturer of KURARISTER™.

The company was established in 1926 in Kurashiki, Japan for the industrial manufacture of chemical fibres. Since then, it has capitalised fully on its technological strengths in the fields of polymerisation and synthetics. Today, the Kuraray Group consists of about 70 companies, employing around 7,000 people worldwide.

Kuraray has been manufacturing and marketing ethylene vinyl-alcohol (EVOH) copolymer resins since 1972. Ever since, EVAL™ - the registered trademark for its EVOH resins - has grown into one of the company’s core businesses.

EVAL Europe nv was founded as a wholly owned subsidiary in Antwerp in 1997 to supply the European, Middle Eastern and African markets with EVAL™. EVAL Europe nv has all the necessary expertise to locally serve European customers from its Technical and Development Centre. The first EVOH production site in Europe doubled its production capacity in October 2004 to 24,000 tons per year.

Building on three decades of expertise in EVOH production, EVAL Europe remains the region’s leading EVOH manufacturer.

Unique technology from Kuraray

Kuraray, Co. Ltd. has developed leading high barrier technologies that are results of Kuraray’s pioneering research and development in this field.

EVAL™ resins are characterised by superior gas barrier properties and excellent coextrusion processability, while being recyclable. Technological innovation has led to an extended range of different grades of EVAL™ resins for food packaging, cosmetics, construction and building, automotive and industrial applications.

EVAL™ EVOH barrier performance to hydrocarbons is about 4,400 times better than that of HDPE and many times greater than that of nylon 6, which makes them ideal for safe, light, durable and environmentally friendly fuel tanks and fuel system components.
Around the world, multilayer plastic fuel tanks and fuel system components have become the preference of automobile designers and manufacturers. Plastic exhibits several advantages over metals, such as its light weight and ease of fabrication. In addition, thanks to the unparalleled barrier performance of EVAL™ resins, these tanks are as good for the environment as they are for industry.

The evolution of automotive fuel tanks

About 40 years ago, all fuel tanks were made of steel. Steel tanks, however, have a number of disadvantages: they are heavy, they risk corrosion and leakage and they cannot be fabricated into unique shapes as easily as thermoplastics. The automotive industry looked for an alternative and turned to plastic.

The first plastic fuel tanks were introduced in Europe during the 1960s and later spread to the US due to the implementation of the LEV1 legislation. Blow-moulded monolayer was the preferred technology for fluorinated fuel tanks, but the introduction of the slosh test soon called for a technology that would give consistent performance over time. This led to the development of six-layer fuel tanks with an EVAL™ EVOH barrier layer, which is now the dominant plastics technology used in the market.

Fluorination and (to a lesser extent) selar technologies remain popular thanks to the fact that manufacturers can apply them to existing monolayer tank structures and machines without significant additional investment. However, from a performance point of view these technologies have some shortcomings: durability, barrier performance and environmental concerns make them less attractive. In the future, they may well be limited by increasingly strict emission and other environmental standards.

In comparison with the other treatments used as barrier material for HDPE fuel tanks, multilayer coextrusion with EVAL™ is the leading technology that meets U.S. EPA and CARB emission standards. Kuraray has already prepared the next generation of EVAL™ barrier technology, capable of taking tank shell performance well beyond Partial Zero Emissions Vehicle (PZEV) requirements.

The multilayer plastic fuel tank advantage

- Stronger and lighter, reducing overall car weight and improving fuel efficiency.
- Safer, reducing the risk of perforation and leakage in a crash.
- More space-efficient, meaning it can be moulded into complex geometries to optimise space.
- Economical to produce, since regrind can be recycled and reused.
- Superior corrosion-resistance at a lower cost.
- Cleaner, producing less waste in the workplace environment.
Why do so many plastic fuel tanks have an EVAL™ barrier layer? The key reason is that EVAL™ resin’s fuel barrier properties are superior to any other conventional polymer.

Plastic fuel tanks can be produced either by coextrusion blow moulding or from thermoformed coextruded sheet. With EVAL™ EVOH, barrier performance to hydrocarbons is about 4,400 times better than that of HDPE and many times greater than that of nylon 6. By largely preventing permeation through the wall of the tank, the EVAL™ gas barrier minimises fuel vapour emissions.

Environmental concern and resulting new regulations have focused on limiting vapour emissions from fuel systems, and the barrier requirements for the plastics used have steadily increased. Adding an EVAL™ layer to a multilayer tank is a cost-effective and reliable way to be in compliance with these international emission standards. Automobile manufacturers worldwide have switched from monolayer plastic and metal to multilayer plastic fuel tanks and with an EVAL™ EVOH layer.

Subsequently, there is an increasing tendency to add EVAL™ barrier properties to other fuel system parts such as filler pipes, fuel lines and fuel tank components.

**Advantages throughout the fuel system**

In addition to their application in automotive and small engine fuel tanks, EVAL™ resins are the ideal solution for a number of fuel system components. EVAL™ functions as an outstanding barrier to HFC, CO₂, N₂ and H₂, which makes EVAL Europe the perfect partner in the development of low emission parts for air conditioning systems, hydrogen fuel cell storage applications, fuel lines and filler pipes.

**Reliability and compliance**

With unparalleled fuel barrier properties, the EVAL™ barrier layer keeps fuel vapour within the walls of the fuel system and out of the atmosphere, in compliance with strict US EPA Tier 1, Tier 2; CARB LEV1, LEV2, PZEV; and European III, IV, V, VI emission standards. EVAL™ is the only EVOH resin compliant with ISO TS 16949.

**Durability**

Highly resistant to hydrocarbons, oils and organic solvents, EVAL™ resins remain durable over time, preventing the evaporation of chemicals.

**Stability**

EVAL™ resins provide good long-term thermal stability, even in high-temperature environments.

**Processability**

Easy to process, EVAL™ resins can be coextruded with HDPE and other component layers on conventional equipment in a single step. A range of grades is available to meet diverse processing requirements (including injection moulding).

**Accessibility**

EVAL™ resins are manufactured and sold by the EVAL Companies of Kuraray in Europe, the Americas, and Asia-Pacific.

**The EVAL™ resins advantage**

- High and ultra-high barrier EVAL™ grades for Flex Fuel.
- Easy and economical to process.
- Complex geometries possible.
- Barrier performance enables production of lighter fuel tanks.
- Improved crash and leak resistance.
- Durability over time in contact with Flex Fuel.
- Regrind can be recycled and reused.
- Compliant with the International Material Data System (IMDS).
- Compliant with ISO TS 16949 and ISO 14001.
The Flex Fuel solution

Since Flex Fuel is becoming more and more popular worldwide, Kuraray has conducted detailed studies concerning the barrier performance of EVAL™ EVOH resins to Ethanol-containing fuels.

An EVAL™ grade with an even better barrier performance towards Ethanol-containing fuel has been developed, and the durability of both standard and new grades towards Flex Fuel has been proven.

EVAL™ resins barrier properties

Excellent resistance to standard and flex fuels

Permeation vs. thickness

Reported results are an average of the permeation of two tanks (70 litre volume).

Soak conditions: 10 weeks at 60°C and 5 weeks at 40°C with E10.

Fuel changed every 4 weeks, at start of 40°C soak, and prior to mini-SHED test.

F101 is 32 mol% ethylene vinyl alcohol copolymer.

M100 is 24 mol% ethylene vinyl alcohol copolymer.

GC-based method at 40°C in Japan using multilayer film (90/10/x/10/90)
EVAL™ used in fuel tanks

Safer than steel

Plastic fuel tanks increase safety in the event of a crash. Unlike metal fuel tanks, plastic tanks can bend and flatten rather than tear, rupture and spill fuel. Because they are more likely to stay intact, they significantly reduce the likelihood of fuel leakage, which can cause a fire or explosion.

More design flexibility

Plastic fuel tanks allow car designers to optimise the space available for the fuel tank because they can be fabricated into virtually any shape. In addition, plastic can be moulded around specific parts and is corrosion-resistant. Only stainless or coated steels can provide an equivalent level of corrosion-resistance, which adds significant costs.

<table>
<thead>
<tr>
<th>Typical applications</th>
<th>Typical structure (in/out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel tanks (automotive)</td>
<td>HDPE/tie/EVAL™/tie/regrind/HDPE + masterbatch</td>
</tr>
<tr>
<td>Small-engine gas tanks (lawn mowers, chain saws, ATVs, marine &amp; motor vehicles)</td>
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</table>

EVAL™ used in fuel line applications

Plastic fuel lines are light weight, cost effective and allow complex geometries, which makes them very appealing for manufacturers. Plastic fuel lines containing an EVAL™ barrier layer provide exceptional permeation resistance, meeting stringent international emission regulations (EURO, EPA and CARB) and durability characteristics. Plastic fuel lines enable manufacturers to optimise the cost, space, weight and fit parameters while surpassing safety and emission requirements.

<table>
<thead>
<tr>
<th>Typical applications</th>
<th>Typical structure (in/out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel lines</td>
<td>PA 6/EVAL™/PA 6/tie/PA 12</td>
</tr>
</tbody>
</table>
The environmentally friendly packaging

EVAL™ EVOH is an environmentally friendly plastic. It contains no chlorine, dioxin, metals or endocrine disrupters. It can be recycled, either as part of a separate coextruded regrind layer or as post-consumer regrind. And it will not disrupt polyolefin or PET recycling streams and processes. Even fully sustainable packaging only has value if it remains functional. EVAL™ EVOH adds real functionality to packaging, and helps lower environmental impact at several stages of the packaging lifecycle. The superior gas barrier properties of EVAL™ protect food quality and prolong freshness and shelf life, reducing waste and unnecessary transport, and allowing significant reduction in the required thickness of packaging structures. Even when compared to other coextruded barrier plastics like PA6, structures containing highly functional EVAL™ can usually lower total material cost even while reducing the thickness and weight of packaging.

European evaporative emission regulations

As environmental issues have become increasingly important, several efforts have been made to improve air quality by limiting pollution from all sources. For many years emission regulations for fuel tanks were defined by only one standard, which was used throughout most of Europe: the ECE R34 (EURO 1), which was related only to fuel tank permeation. In 1996 a new regulation EURO 2 was set up and stated that emissions of the total vehicle – instead of only the fuel tank – should not surpass 2 grams/cycle. EURO 3, introduced in 2000 and effective in 2001 as Directive 98/69/EC, was based on the US regulation and limited emission to 2g per 24 hours for the entire vehicle. EURO 4 limits were introduced in 2005 and became fully effective on 1 January, 2007. It repeated the 2g/24 hour SHED limit, and focused more on tail pipe emissions. EURO 5 will be introduced in 2009, taking full effect in 2011. It is expected that the same 2g/24 hour SHED limit will be maintained, but when using fuels containing 5% ethanol. This change to more challenging fuels will further highlight the effectiveness of EVAL™ barrier properties in comparison to other plastic fuel system solutions.

Similar requirements were adopted for diesel cars and light and heavy commercial vehicles.

Overview of the European evaporative emission regulations

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Date effective</th>
<th>Emission level</th>
</tr>
</thead>
<tbody>
<tr>
<td>EURO 1</td>
<td>1993</td>
<td>20.0g/24 hours (weight loss)</td>
</tr>
<tr>
<td>EURO 2</td>
<td>1996</td>
<td>2.0g/hour diurnal (SHED)</td>
</tr>
<tr>
<td>EURO 3</td>
<td>2001</td>
<td>2.0g/24 hours diurnal (SHED)</td>
</tr>
<tr>
<td>EURO 4</td>
<td>2007</td>
<td>2.0g/24 hours diurnal (SHED)</td>
</tr>
</tbody>
</table>

Overview of the US evaporative emission regulations

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Regulatory agency</th>
<th>Emission allowed on light duty vehicle</th>
<th>Tested item</th>
<th>Useful life required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1</td>
<td>EPA</td>
<td>2000 mg/test for 3 day diurnal</td>
<td>Entire vehicle</td>
<td>100,000 miles</td>
</tr>
<tr>
<td>Tier 2</td>
<td>EPA</td>
<td>950 mg/test for 3 day diurnal</td>
<td>Entire vehicle</td>
<td>120,000 miles</td>
</tr>
<tr>
<td>LEV I</td>
<td>CARB</td>
<td>2000 mg/test for 3 day diurnal</td>
<td>Entire vehicle</td>
<td>100,000 miles</td>
</tr>
<tr>
<td>LEV II</td>
<td>CARB</td>
<td>500 mg/test for 3 day diurnal</td>
<td>Entire vehicle</td>
<td>150,000 miles</td>
</tr>
<tr>
<td>PZEV</td>
<td>CARB</td>
<td>350 mg/test for 3 day diurnal</td>
<td>Entire vehicle</td>
<td>150,000 miles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>54 mg/test for 3 day diurnal</td>
<td>Fuel system</td>
<td></td>
</tr>
</tbody>
</table>

SHED data shows <15mg/24hr tank wall
EVAL™ ethylene vinyl alcohol (EVOH) copolymer resins provide outstanding gas barrier properties and excellent processability. The key to this balance of characteristics is the proper copolymerisation ratio of ethylene to vinyl alcohol. Kuraray’s unique proprietary manufacturing process has produced the world’s widest available range of EVOH grades.

EVAL™ M type has the lowest ethylene content available, and provides the highest barrier for automotive fuel systems.

EVAL™ L type has a very low ethylene content and is suitable as an ultra high-barrier grade in flexible, bottle and sheet applications.

EVAL™ F type offers superior barrier performance with long-term run stability, and is widely used as the standard grade for flexible, automotive, bottle and tube applications. Specific versions exist for coating and pipe applications.

EVAL™ T type was specially developed to obtain reliable layer distribution in thermoforming, and has become the industry standard for multilayer sheet and thermoformed flexible applications.

EVAL™ J type offers thermoforming results even superior to those of T, and can be used for unusually deep-draw or sensitive sheet-based applications.

EVAL™ C type can be used for high-speed coextrusion coating and cast flexible applications.

EVAL™ H type combines high barrier properties with long-term run stability and thermoformability. The higher ethylene content allows easier processing and longer running times on older coextrusion equipment, especially for blown flexible structures.

EVAL™ E type has a higher ethylene content that allows for greater flexibility and even easier processing.

EVAL™ G type has the highest ethylene content, making it the best candidate among standard EVAL™ grades for stretch and shrink film applications.

Scale of ethylene content (mol%)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>2 4</td>
<td>24 mol%</td>
</tr>
<tr>
<td>L</td>
<td>2 7</td>
<td>27 mol%</td>
</tr>
<tr>
<td>F</td>
<td>3 2</td>
<td>32 mol%</td>
</tr>
<tr>
<td>T</td>
<td>3 5</td>
<td>35 mol%</td>
</tr>
<tr>
<td>J</td>
<td>3 8</td>
<td>38 mol%</td>
</tr>
<tr>
<td>C</td>
<td>4 4</td>
<td>44 mol%</td>
</tr>
<tr>
<td>H</td>
<td>4 8</td>
<td>48 mol%</td>
</tr>
<tr>
<td>E</td>
<td>4 6</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>4 9</td>
<td></td>
</tr>
</tbody>
</table>
EVAL™ used in pipe applications

Compared to their metal equivalents, multilayer plastic fuel filler pipes are lighter in weight and more flexible than conventional steel pipes. This gives manufacturers greater freedom in the positioning of the fuel tank underneath the car to optimise safety and design while reducing the overall weight of the vehicle.

The barrier properties of an EVAL™ layer add superior barrier performance to the fuel filler pipes and to the entire fuel system. An EVAL™ layer in a multilayer fuel filler pipe reduces the gas permeation to an absolute minimum, meeting strict international emission standard regulations.

### EVAL™ layer advantages
- Excellent fuel vapour barrier.
- Resistance to gasoline.
- Complex geometries are possible.
- Environmental-friendly, since regrind is reused and there is minimal gasoline vapour permeation.

### Processing method
- Extrusion blow moulding (3-D).
- Pipe coextrusion.

### Typical applications

<table>
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<tr>
<td>Fuel filler pipes</td>
<td>HDPE/tie/EVAL™/tie/regrind/HDPE + masterbatch</td>
</tr>
<tr>
<td>Underground fuel pipes</td>
<td>EVAL™/tie/HDPE</td>
</tr>
</tbody>
</table>

### EVAL™ barrier to hydrogen

Hydrogen fuel cells present a promising technology that can provide energy for stationary applications, for mobile use in transport and even power generation for a laptop or camcorder. Hydrogen fuel cells are environmentally friendly since they do not produce polluting emissions or greenhouse gases.

Over the next ten years, it is expected that fuel cells will be commercially introduced into several transportation and utility power markets, requiring reliable and high-performance barriers to hydrogen gas.

### EVAL™ EVOH resins

EVAL™ EVOH resins can be used to ensure very low-hydrogen gas permeation in hydrogen storage and fuel cell systems.

### Advantages of EVAL™ layers in multilayer plastic hydrogen tanks
- Substantially less weight than with steel tanks.
- The barrier against hydrogen is 1,000 times better than that of polypropylene.
- Environmentally friendly and recyclable.
- Fewer raw materials are required for the same results.

### Ethylene mol% and H₂GTR - cc/m²·d·atm for 0.1 mm - 20°C, 0% RH

<table>
<thead>
<tr>
<th>Ethylene mol%</th>
<th>H₂GTR - cc/m²·d·atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVAL™ 24 mol%</td>
<td>3</td>
</tr>
<tr>
<td>EVAL™ 32 mol%</td>
<td>6</td>
</tr>
<tr>
<td>EVAL™ 44 mol%</td>
<td>40</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>2,000</td>
</tr>
</tbody>
</table>
EVAL™ the world’s leading EVOH

Europe
EVAL Europe nv (Antwerp, Belgium)
Capacity: 24,000 tons/year
Europe’s first and largest EVOH production facility

Americas
EVAL Company of America (Pasadena, Texas, USA)
Capacity: 35,000 tons/year
The world’s largest EVOH production facility

Asia-Pacific
Kuraray Co. Ltd. (Okayama, Japan)
Capacity: 10,000 tons/year
The world’s first EVOH production facility

Building better barriers

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EVAL™ resins are produced worldwide under unified Kuraray product and quality specifications.