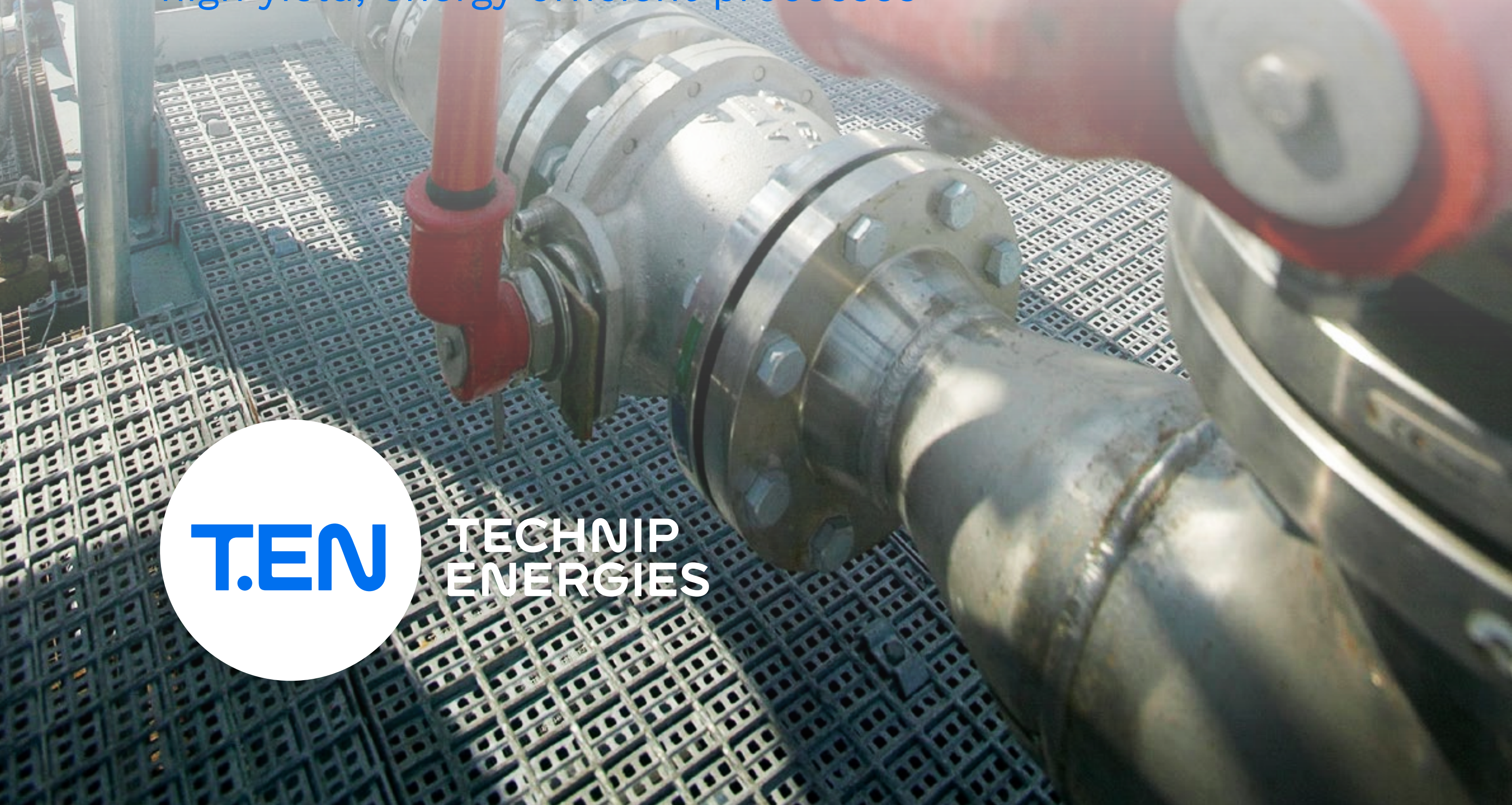
Where energies make tomorrow

Styrenics

Ethylbenzene, Styrene Monomer, Acrylonitrile Butadiene Styrene and Polystyrene technologies

Badger Ethylbenzene (EBMax^{SM}), Styrene, ABS, Polystyrene and associated bolt-on technologies – worldwide standard for high yield, energy efficient processes



T.EN TECHNIP ENERGIES

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Ethylbenzene (EBMax[SM])

The Badger Ethylbenzene technology (EBMax℠) has gained acceptance as the worldwide standard for EB production. The Badger technology is a high yield and highly energy efficient process. Capital investment and operating costs are low and the EBMax process is easy to operate and maintain.

Technip Energies and ExxonMobil have a 40-year history of cooperation in the development of catalysts and processes to produce high quality ethylbenzene from polymer grade ethylene, chemical grade ethylene, and ethylene recovered from refinery off-gas. Since its commercialization in 1995, the EBMax technology has been licensed 40 times, both for new plants and the expansion and conversion of plants based on earlier technologies to EBMax technology. The exceptional properties of ExxonMobil's EBMax catalysts allow operation with a minimal excess of benzene in the alkylation and transalkylation reactor feeds, reducing capital investment and energy consumption in the reaction and distillation sections of the EB plant.

Alkylation

An alkylation reactor system converts benzene and ethylene to ethylbenzene in the liquid phase. ExxonMobil's specialized Reactive Guard Bed technology helps achieve long catalyst life.

Transalkylation

A transalkylation reactor converts the small amount of polyethylbenzenes (PEB) formed in the alkylator to additional ethylbenzene by reaction with benzene in the liquid phase.

Purification

A simple energy efficient distillation train is used to return unreacted benzene to the reactors, recover ethylbenzene product and recover PEB for conversion to EB in transalkylation.

The ethylbenzene produced contains less than 100 ppm of xylene plus propylbenzene impurities. Product purities of 99.95-99.99% are regularly achieved in commercial operation.

Ethylbenzene technology highlights

LOW VARIABLE OPERATING COST

- Ultra-high (nearly stoichiometric) yields minimize raw material consumptions
- Low benzene-to-ethylene ratio reduces capital investment and consumption of HP steam
- High energy efficiency and seamless integration with downstream styrene units

LOW INITIAL CAPITAL INVESTMENT

- Smaller benzene recovery equipment
- Small reactors and catalyst volumes
- Optimized equipment layout and plot plan

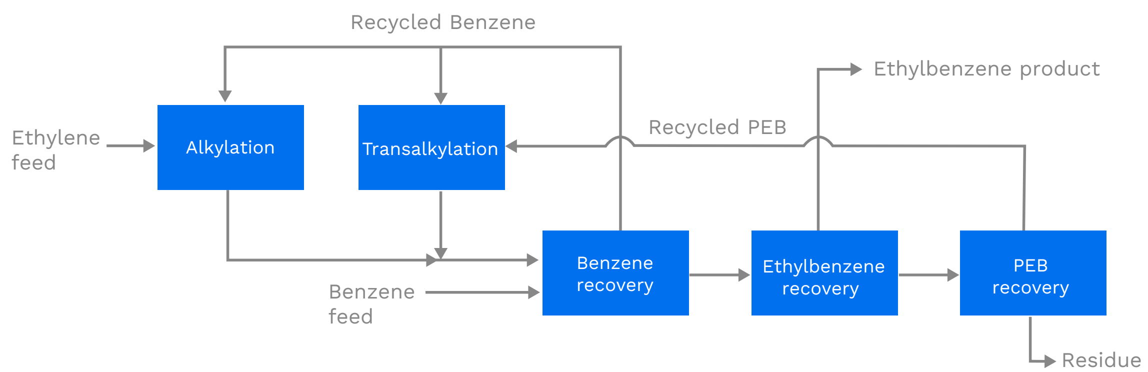
COMMERCIAL EXPERIENCE

- As of early 2020, plants using Badger Ethylbenzene technologies produce over half of the world's ethylbenzene capacity having a total installed capacity of more than 23 million metric tons per year.
- Single trains as large as 1.4 million MTA have been demonstrated.
- Technip Energies and ExxonMobil assist producers with troubleshooting, plant monitoring, and potential plant expansions.

Our Catalyst Provider: ExxonMobil

ExxonMobil Catalysts and Licensing LLC (EMCL)'s zeolite catalyst research and development capabilities are unsurpassed within the industry. Supported by basic research activities at its R&D facilities and pilot plant facilities used to screen new catalysts, EMCL is a recognized leader in the development and commercialization of new zeolite catalytic materials. EMCL's commercial catalyst production plants maintain the highest quality control standards. The exceptional characteristics of the EBMax catalysts benefit the process as follows:

- EMCL's proprietary zeolite alkylation catalyst does not age due to coking caused by ethylene oligomerization, resulting in long, uninterrupted EBMax unit operation.
- The alkylation catalyst is highly selective to monoalkylation, which has allowed commercial operation at design benzene-to-ethylene molar feed ratios as low as 1.6-to-1 for plant expansion projects.
- The reaction system produces extremely low levels of impurities boiling in the range of EB, resulting in EB product purities in excess of 99.97 wt%.
- EMCL's proprietary guard bed catalyst removes traces of nitrogen-containing compounds which would otherwise poison the process catalysts, minimizing the frequency of catalyst regeneration.



As a leader in styrene technology for more than 55 years, Badger's name has become synonymous with energy efficiency, reliability, and long on-stream times. Together with our operating partner TotalEnergies, we have developed a technology that operates at an ultra-low steam-to-oil ratio in the reactors with the longest operating runs between catalyst changes in the industry.

Styrene process

Low steam-to-oil, combined with our patented **Multi-Effect Distillation** and **Catalyst Stabilization** technologies, results in a low variable operating cost. Deep vacuum in the reactor section, together with low distillation temperatures, result in high styrene product yield. Licensed units using our styrene technology represent approximately half of the styrene monomer produced via ethylbenzene dehydrogenation. Technip Energies Badger Process Technology's continued innovation in styrene unit design, such as **Direct Heating Unit (DHU)** technology, is second to none.

REACTION

A two-stage dehydrogenation reaction system converts ethylbenzene to styrene.

PURIFICATION

- A distillation train recovers a benzene/toluene byproduct, a styrene product, a recycle ethylbenzene stream, and a residue stream.

Styrene Technology Highlights

LOW VARIABLE OPERATING COST

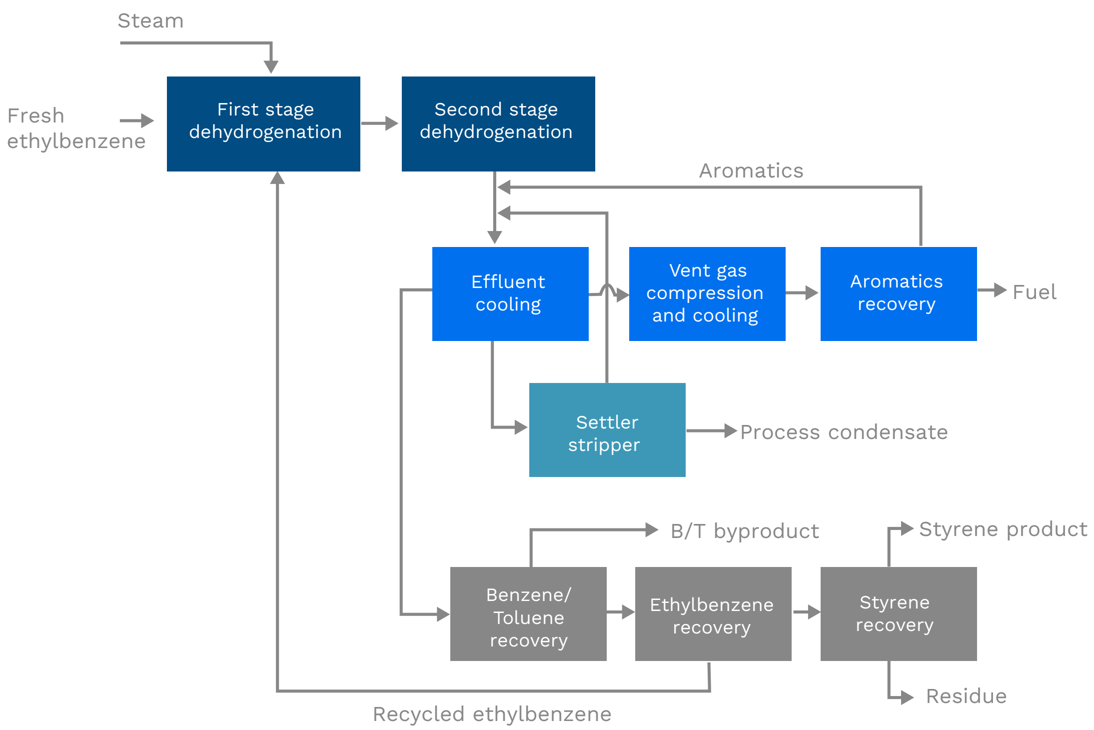
- Low steam-to-oil reaction operation
- Low pressure results in high yields
- Catalyst stabilization extends run life

COMMERCIAL EXPERIENCE

- As of early 2020, Technip Energies Badger Process Technology has licensed plants representing almost half of the world's styrene manufactured by ethylbenzene dehydrogenation.
- Single train operating experience as high as 770 KTA
- Extensive feedback from operating plants

SUPERIOR TECHNOLOGY

- Demonstrated superior mechanical integrity
- External reactor reheat exchanger for easy access and maintenance
- Vertical feed/effluent exchanger provides constant pressure drop and compact design
- Low steam superheater outlet temperatures
- Low polymerization inhibitor consumption
- Equipment layout facilitates capacity expansion
- Multi-Effect Distillation (MED) significantly reduces the energy consumption



Direct Heating Unit technology

Direct Heating Unit (DHU) Technology is a groundbreaking improvement to the styrene industry. This technology for adding heat to high temperature processes employs flameless combustion for the dehydrogenation of ethylbenzene to styrene. Unlike conventional furnace burners, where fuel and air are combined at a single point, in a DHU unit, fuel is added incrementally to a high velocity air stream over an extended reaction zone. This allows the fuel to react in a controlled manner at significantly lower temperatures than flame combustion. Technip Energies supplies the Process Design Package, field services, the DHU equipment, as well as the technology license for the unit.

BENEFITS OF DHU TECHNOLOGY:

- Combines the functions of a steam superheater cell and a reheat exchanger
- Fewer high temperature pipes
- Reduces steam consumption
- Less plot space
- Less pressure drop for both steam and the process
- Replaces a fired heater with a heat exchanger
  - Fewer interlocks
  - Less complex controls
  - Easier to operate
  - Inherently safer

Catalyst Stabilization technology

Licensed exclusively by Technip Energies Badger Process Technology, Catalyst Stabilization technology (CST) significantly extends the useful life of the dehydrogenation catalyst by replenishing the potassium promoter. Having been licensed to 31 styrene units (including 17 units since 2010), CST has proven to be a cost-effective solution for reducing the frequency of catalyst replacement. CST is now licensed to almost 50% of the world's licensable dehydrogenation capacity.

Benefits of CST include:

- Catalyst activity no longer determines when to schedule turnarounds
- Fewer turnarounds, which means less lost production

Phenylacetylene Reduction

Phenylacetylene Reduction (PAR) technology has been jointly developed by TotalEnergies and Technip Energies Badger Process Technology to produce a styrene product with very low phenylacetylene (PA). Low PA in the styrene product provides the end-user the opportunity for market differentiation. A small amount of hydrogen is added in a catalytic process to convert PA back to ethylbenzene. PAR has been licensed 10 times.

Compressor Suction Chilling

Compressor Suction Chilling (CSC) technology is a patented method for treating vent gas. The vent gas is cooled by contact with chilled water. CSC technology is ideal for small capacity expansions and has the added benefit of reduction in polymer fouling in the vent gas equipment.

OUR PARTNER: TOTALENERGIES

TotalEnergies Refining & Chemicals' research facilities, together with the five operating units of TotalEnergies, are invaluable resources to the development and commercialization of styrene process improvements. Access to the operating plants also allows for demonstration of new or innovative concepts such as DHU.

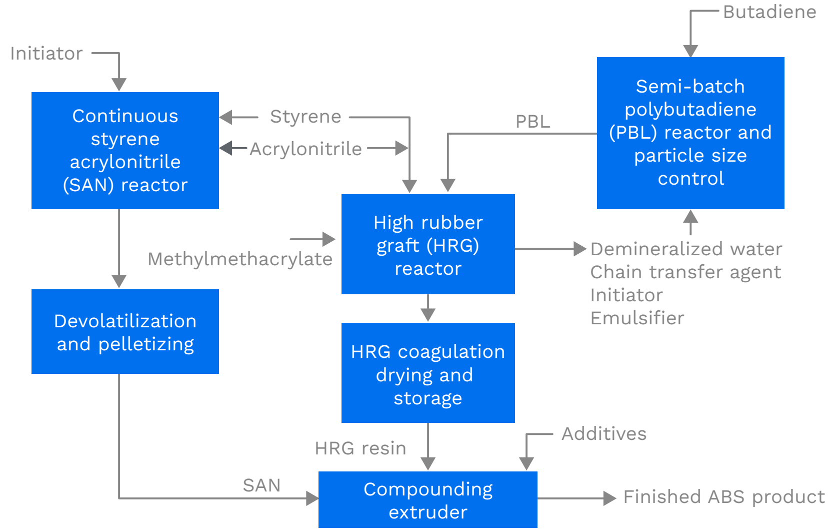
ABS technology

The ABS technology is comprised of four process elements: polybutadiene latex polymerization (PBL), high-rubber graft (HRG) polymerization and isolation, styrene acrylonitrile (SAN) polymerization, and final product compounding. The properties of ABS can be widely varied by using different concentrations of butadiene rubber and acrylonitrile in the copolymer.

Changes and improvements

Recent changes and improvements in the technology have led to better quality, improved environmental performance and a 25-35 percent reduction in total investment cost compared to previous generations of the technology. These changes include:

- In the PBL area, an improved mechanical agglomeration process resulted in a 100 percent increase in throughput per unit compared to the previous generation.
- In the HRG and PBL areas, the reaction process was improved resulting in a 25 percent increase in capacity per reactor from previous designs.
- In the SAN area, significant debottlenecking of previous designs achieved a 90 percent increase in production rates and better resin quality.
- In the compounding area, implementation of an improved extrusion process resulted in a 120 percent increase in throughput per line.
- A newly developed water recycle system inside the battery limits of the HRG plant recycles 90 percent of the water and reduces waste water effluent by 90 percent.
- A new design on the HRG dryer dust collector reduces air pollution from dust in the vent vapors. A much broader portfolio of SABIC products outperforms older products.
- Advanced analytical technologies improve quality consistency control.



As the exclusive licensor of the SABIC ABS technology, Technip Energies offers two distinct ABS processes for license: A highly versatile emulsion process and a lower capital cost mass process.

Acrylonitrile butadiene styrene (ABS)

Acrylonitrile butadiene styrene (ABS) is a key thermoplastic used in the electronics, appliances, building, construction and transportation industries. Technip Energies is the exclusive worldwide licensor of SABIC's state-of-the-art ABS technology.

Cycolac™ ABS emulsion technology

Cycolac™ ABS resin is a terpolymer formed by blending a copolymer of acrylonitrile (A) and styrene (S) with an elastomeric component that is either polybutadiene or a butadiene copolymer (B). Using three monomers allows for greater flexibility in the ability to tailor a broad range of end-use requirements.

Cycolac™ ABS emulsion technology benefits:

- Excellent HSE performance that exceeds current North American regulatory requirements
- Inherently safe reaction processes
- High reactor productivity
- Exceptional product quality
- A broad family of products to meet the most demanding applications
- Competitive capital and operating costs
- Commitment to process and product development

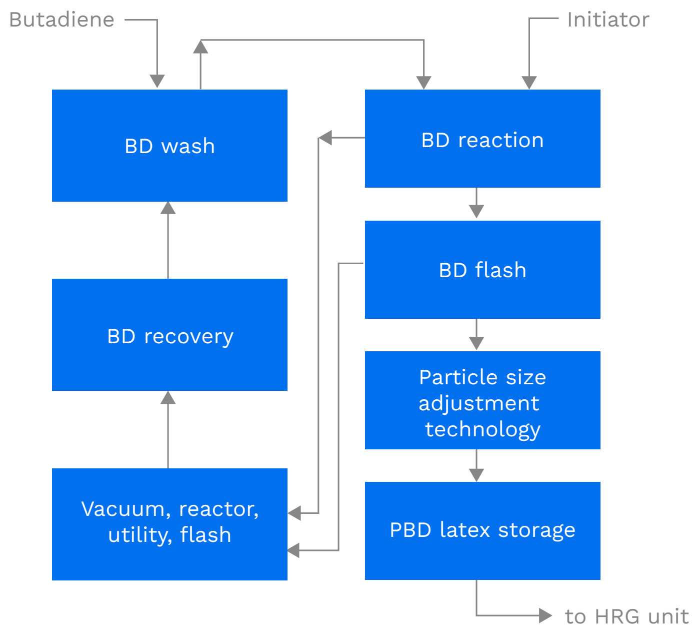
Polybutadiene process

The semi-batch polybutadiene process (PBL) is a unique patented technology that produces the key building block that differentiates SABIC's process and products from the competition. The process has been in service for more than 10 years at two production sites, representing more than 100 reactor years of operation.

The SABIC/Technip Energies process provides these advantages:

REACTOR CAPABILITY

- Higher reactor volume use due to a semi-batch process. About 85 to 90 percent of available working capacity is used compared to a typical batch process that uses 70 to 75 percent
- Significantly shorter reaction cycle compared to standard batch and direct growth technologies (8 hours versus 18-48 hours)
- Clean reactor technology requires only one shutdown per quarter
- Even heat load and patented technology to improve heat transfer resulting in lower cooling water demand
- Higher reactor productivity meaning fewer reactors and lower capital cost
- An efficient monomer recovery process and outstanding emulsion stability resulting in a process yield greater than 99.5 percent



HEALTH, SAFETY AND ENVIRONMENTAL PERFORMANCE

- Fail-safe technology: The exothermic reaction stops when feeds are stopped
- Semi-batch operation results in lower monomer inventory and reduced runaway reaction potential

PRODUCT

- One polybutadiene product results in a simplified and cost-effective operation
- Bi-modal particle-size distribution means improved flow/impact balance and low emulsifier non-polymer impurities in the final product

High Rubber Graft process

A semi-batch resin process, the high rubber graft process (HRG) is a patented process technology. The process has been in service for 15-plus years at three production sites without a major safety incident. This represents more than 150 reactor years of operation.

The HRG reaction process, a semi-batch emulsion reaction of styrene and acrylonitrile with PBL, is followed by a continuous coagulation to form resin particles, to remove water and to dry the HRG product. A major process chemistry improvement now minimizes emissions and maximizes conversion.

REACTOR CAPABILITY

- Significantly shorter reaction cycle compared to standard technologies (4.25 hours versus 8-16 hours)
- Significantly higher rubber content allows for lower HRG usage and results in lower capital and operating costs
- Special reactor cleaning technology reduces reactor cleaning shutdowns to once a year

HEALTH, SAFETY AND ENVIRONMENTAL PERFORMANCE

- Fail-safe technology: The exothermic reaction stops when feeds are stopped
- Semi-batch operation means lower monomer inventory and reduced runaway reaction potential
- Patented technology results in higher monomer conversion (>99.8 percent), resulting in lower emissions and higher yield

PRODUCT

- One high rubber graft product results in a simplified and cost-effective operation
- Optimized impact flow performance with low organic volatiles and non-polymer impurities

Styrene Acrylonitrile process

The styrene acrylonitrile process (SAN) has been in service for more than 30 years without a major process safety incident. The process was recently optimized to improve productivity and product quality.

SAN is a copolymer plastic consisting of styrene and acrylonitrile. It is widely used in place of polystyrene due to its greater thermal resistance. The SAN polymer is produced in a single agitated reactor.

REACTOR CAPABILITY

- Continuous reaction process means high reactor productivity
- Efficient reaction and monomer recovery process results in a >99% yield
- Robust and flexible process allows for multiple comonomers and various percent acrylonitrile content

HEALTH, SAFETY AND ENVIRONMENTAL PERFORMANCE

- Chemically initiated reaction minimizes reaction runaway potential
- No solvents in manufacturing or cleaning processes results in very low emissions with an integral vapor recovery system in process design

PRODUCT

- Chemically initiated technology results in excellent color, low residual monomers, low oligomers, narrow molecular weight distribution and good impact-flow balance
- Versatile process technology allows production of polymer products with acrylonitrile content up to 34 percent
- Process technology allows production of a wide variety of molecular weight polymers with the ability to rapidly transition between products

ABS Compounding process

The finished ABS product is formulated in the compounding area using an extruder. The ABS compounding extrusion process provides the best quality product while minimizing energy usage. It also provides maximum product flexibility and cost-effective production.

COMPOUNDING EXTRUDERS

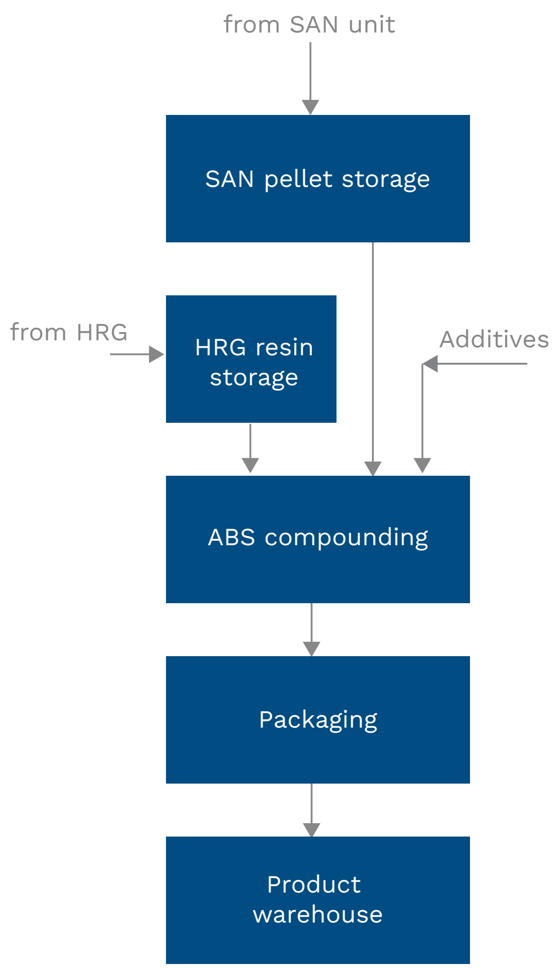
- Optimized extruder sizes from 70 mm to 133 mm for flexibility and maximum productivity
- Reduced investment by optimizing production line capacity based on product families
- Robust rework capability to maximize yield

HEALTH, SAFETY, AND ENVIRONMENTAL PERFORMANCE

- Advanced compositional control ensures oxidative stability during processing to improve operational safety
- Low emissions due to optimization of polymer intermediates and vacuum vent system

PRODUCT

- Product portfolio with more than 24 grades meets all customer requirements
- Additive flexibility allows easy development of specialty products
- Natural/black/white to custom colors are achievable
- Vacuum venting results in low residual monomer levels and reduced non-polymer impurities
- Excellent product portfolio is available for general purpose moulding and extrusion; high heat ABS; building and construction grades; appliances; fire retardant ABS; and specialty grades for antistatic and low-high gloss applications



Technip Energies is the exclusive worldwide licensor of TotalEnergies' state-of-the-art polystyrene technologies including general purpose polystyrene (GPPS) and high impact polystyrene (HIPS)

With 45 years of manufacturing, licensing and research and development experience, TotalEnergies is the second largest producer of polystyrene in the world. TotalEnergies has seven operating plant sites with a combined capacity of nearly 1.5 million metric tons per annum (MTA) including the largest single polystyrene production unit in the world. The polymers produced serve a wide range of applications from packaging, food service and electronics to housewares and insulation.

Through an exclusive alliance, Technip Energies Process Technology licenses TotalEnergies' general purpose polystyrene (GPPS) and high impact polystyrene (HIPS) technology on a worldwide basis. In addition to licensing to third parties, we prepare technical offerings and Process Design Packages and support clients during project execution and plant operation.

Technology highlights

CONTINUOUS MASS POLYMERIZATION PROCESS

- Multiple reactor configurations supported by advanced simulation tools
- Short, smooth grade transitions
- Reliable, efficient operation
- Consistent, predictable quality
- Wide range of capacities and reactor volumes
- Extensive experience in debottlenecking existing lines
- Continuous process development supported by licensing team

LOW CAPITAL INVESTMENT

- Know-how for building facilities at minimum capital cost
- Major equipment is carbon steel: efficient removal of air/water
- Optimized plot and building requirements

SUPERIOR PRODUCT PERFORMANCE

- Wide range of competitive GPPS and HIPS products
- High-quality products, with solid reputation
- Versatile product line, easily customized
- Low polymer volatile content exceeds food packaging requirements
- Continuous product development supported by global R&D efforts

LOW OPERATING AND MAINTENANCE COSTS

- Industry leading onstream performance
- High-efficiency heat transfer system
- No process steam required
- High polymer yields (typically 99 percent or greater)
- Simple process control scheme
- Low raw materials and utility requirements

POLYSTYRENE PLANT EFFICIENCY

Typical raw material and utility consumptions per ton of HIPS

Raw materials	1006 kg
Electric power	120 kwh
Fuel, 80% efficiency	140,000 kCal
Cooling water circulation	100 m^3
Nitrogen	7 Nm^3
Instrument air	25 m^3

A CONTINUOUS MASS POLYMERIZATION PROCESS

A polystyrene plant includes sections for feed preparation, polymerization, devolatilization and pelletization. Typically, a unit designed for HIPS can produce GPPS with a few procedural changes. For HIPS production, polymerization of styrene grafted to polybutadiene rubber produces high impact polystyrene. Variation of the feed composition and process conditions allows a variety of grades to be manufactured. For the dedicated production of consistent high quality GPPS, a specific low capital cost reactor configuration is available.

FEED PREPARATION

For the production of general purpose grades, specific ratios of styrene monomer and mineral oil are prepared upstream of polymerization. High impact grades require the preparation of a polybutadiene rubber solution dissolved in the styrene monomer feed. The ratio of the feed components and selected additives is dependent on the desired grade properties.

POLYMERIZATION

The technology is based on a proprietary polymerization process that employs specialized reactor designs. The technology that produces both GPPS and HIPS includes continuous stirred tank reactors (CSTR), plug flow reactors (PFR) and/or a combination. Reactions can be either thermally or chemically initiated. Single line capacities ranging from 10,000 to 250,000 MTA are available for license. Upstream of the reactors, feed and recycle are combined and preheated. Typically, polymerization occurs stepwise in multiple (CSTR or PFR) reactors arranged in series. Residence time, initiator and reactor temperature profile are controlled to achieve the target conversion rate and finished product properties.

DEVOLATILIZATION

Polymer melt from the reactors is directed to the devolatilization system, which consists of preheating and devolatilizing steps. To facilitate separation of polymer and unreacted monomer, the temperature of the polymer melt is increased. To avoid product degradation caused by high temperature, residence time is minimized. Devolatilization operates under vacuum conditions resulting in low residual styrene monomer levels.

PELLETIZATION

The selection of the technology for pelletizing is based on local market and customer preference. Pelletization technologies including dry cut, wet cut and underwater cut are available. The finished polystyrene pellets are pneumatically conveyed to storage and packaging.

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