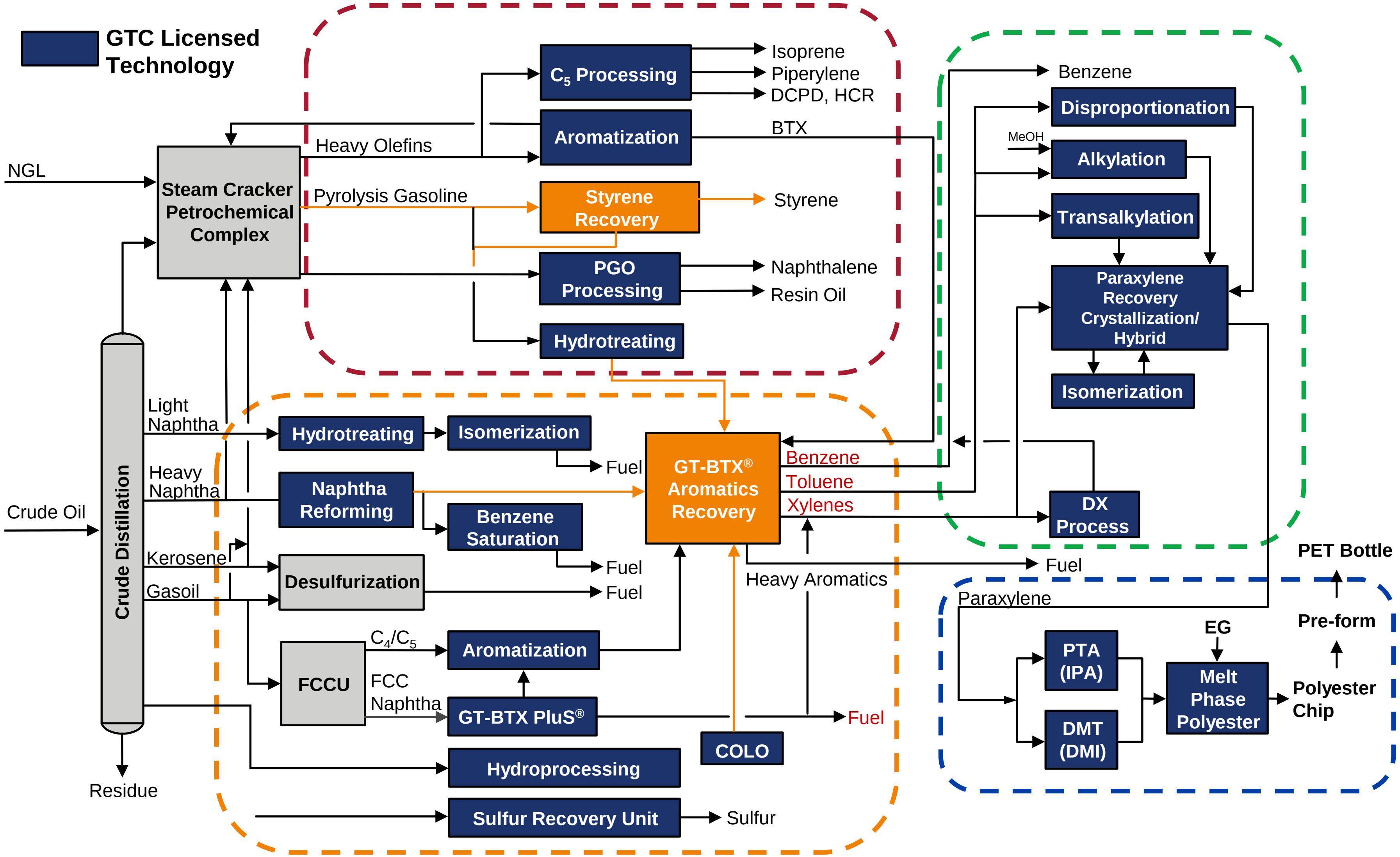
Sulzer GTC Technology

Steam Cracker: Fresh and Recycle feed Optimization and Pygas Upgrade

Sulzer GTC Portfolio

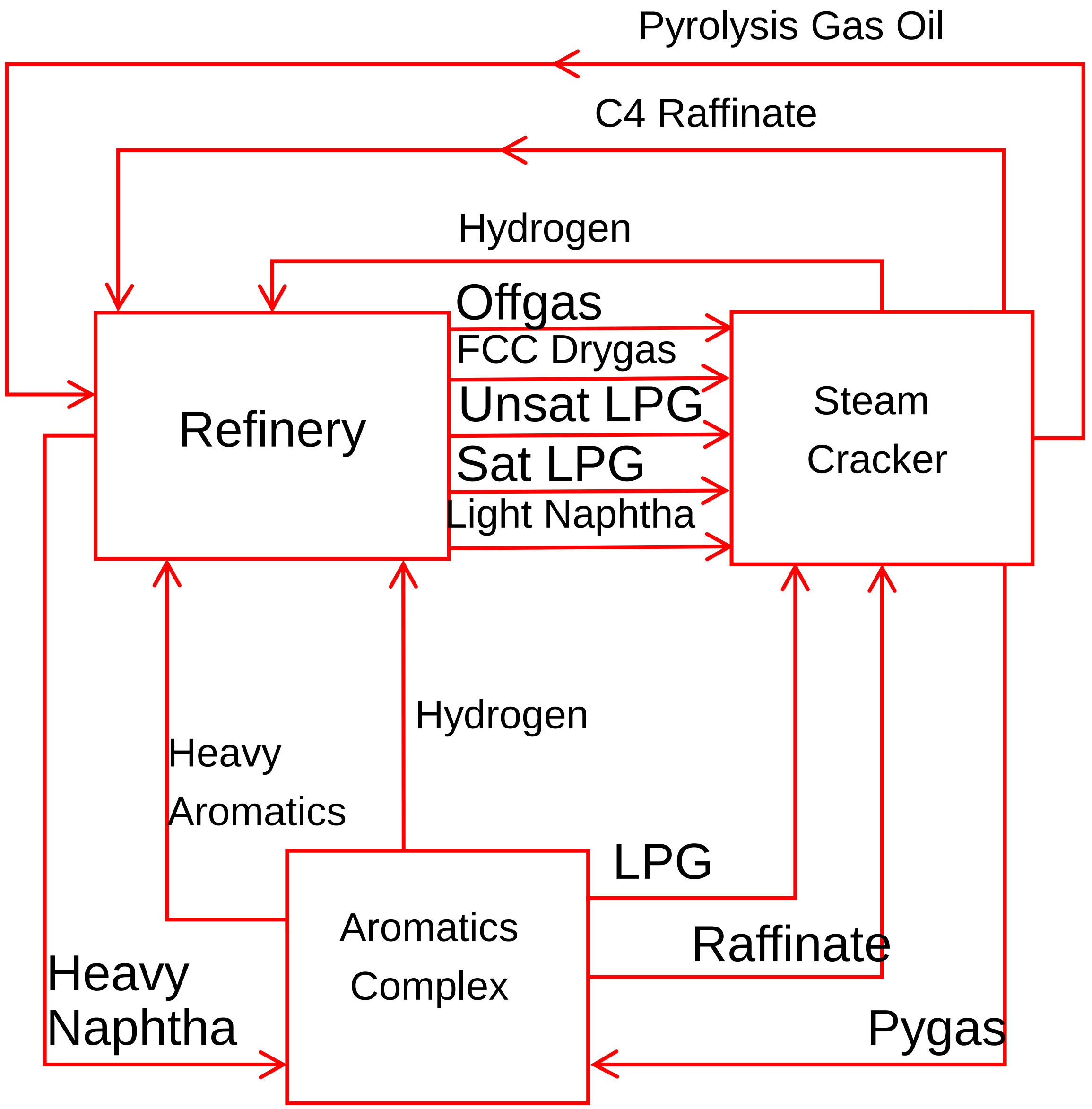


Application of C4 and C5 Reverse Isomerization for Ethylene Cracker Feedstock Optimization

Integrated refining/aromatics/olefins complex

LPG and light naphtha generated in refinery and aromatics complex (from both straight-run and conversion units) are sent to ethylene cracker as feedstock;

More i-paraffin than n-paraffin in LPG and light naphtha generated from hydrocracker and reformer, in particular for i-butane and i-pentane;



Yield difference between cracking i-paraffin and n-paraffin

When cracking i-paraffin and n-paraffin separately in ethylene cracker, the yield of ethylene and propylene is different.

N-paraffin can generate 20wt% of “ethylene + propylene + butadiene” than i-paraffin.

Decoking cycle of ethylene cracker is improved when cracking n-paraffin over i-paraffin.

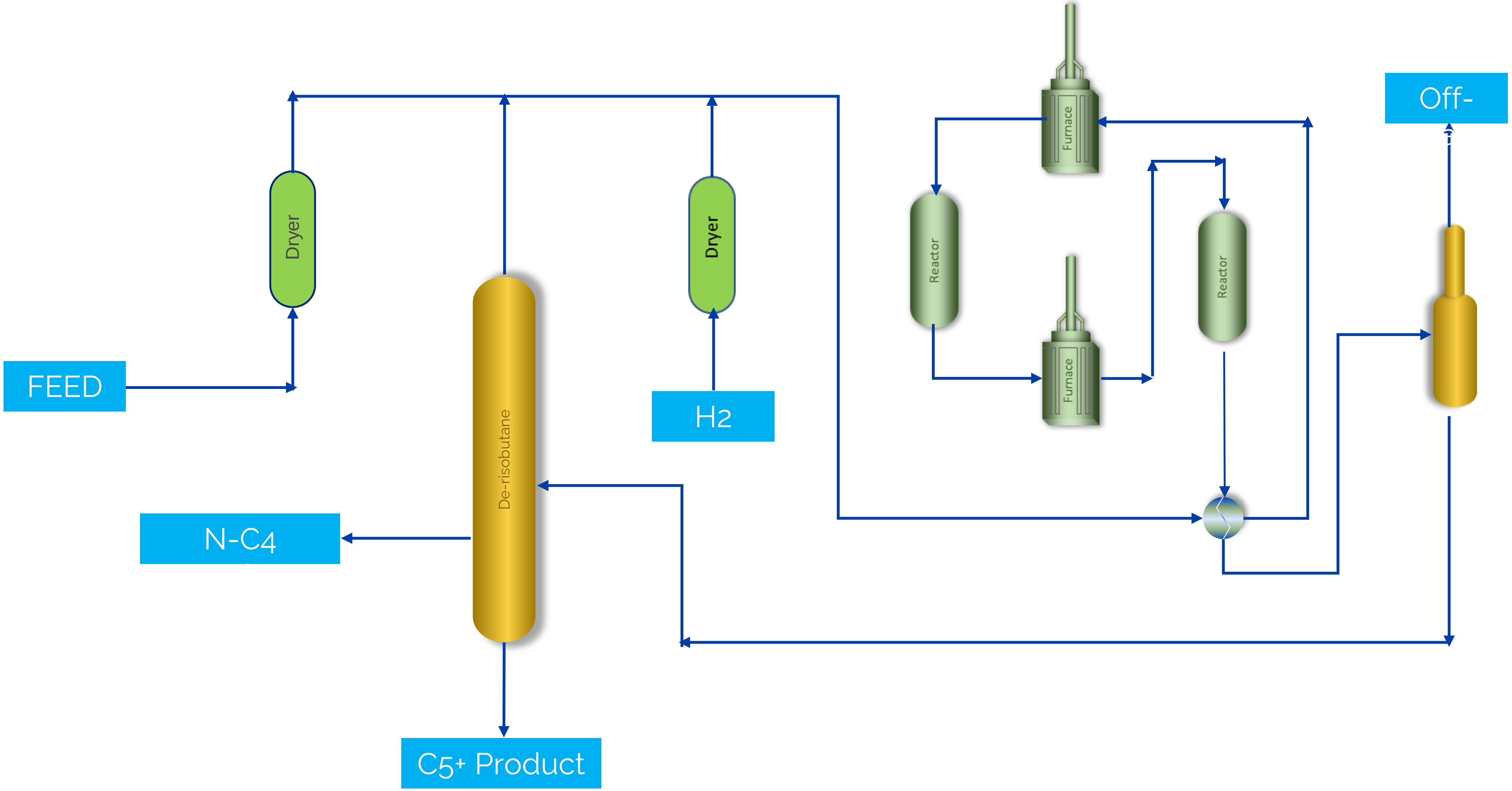
Component	Yield, wt% (n-paraffin feed)	Yield, wt% (i-paraffin feed)
Ethylene	37.3	21.5
Propylene	16.4	14.2
Butadiene	3.5	2.8
Total	**57.2**	**36.5**

iC4-normalization

- Reversible reaction.
- Thermodynamic equilibrium limited.
- Reactor outlet is mixture of i-paraffin and n-paraffin, depending on what the target product is, unconverted reactant (could be either i-paraffin or n-paraffin) is recycled back to reactor combing with fresh feed.
- Bifunctional catalysts required (acid and precious metal)

chemical hydrogen consumption	%	0.08-0.10
n-C4 Yield	%	80-90
Single-pass i-butane conversion across reactor	%	45-50
Single-pass n-butane selectivity across reactor	%	85-90
n-C4 Product Purity.	%	≮95
catalyst service life	years	12-14
catalyst regeneration cycle	years	≮4

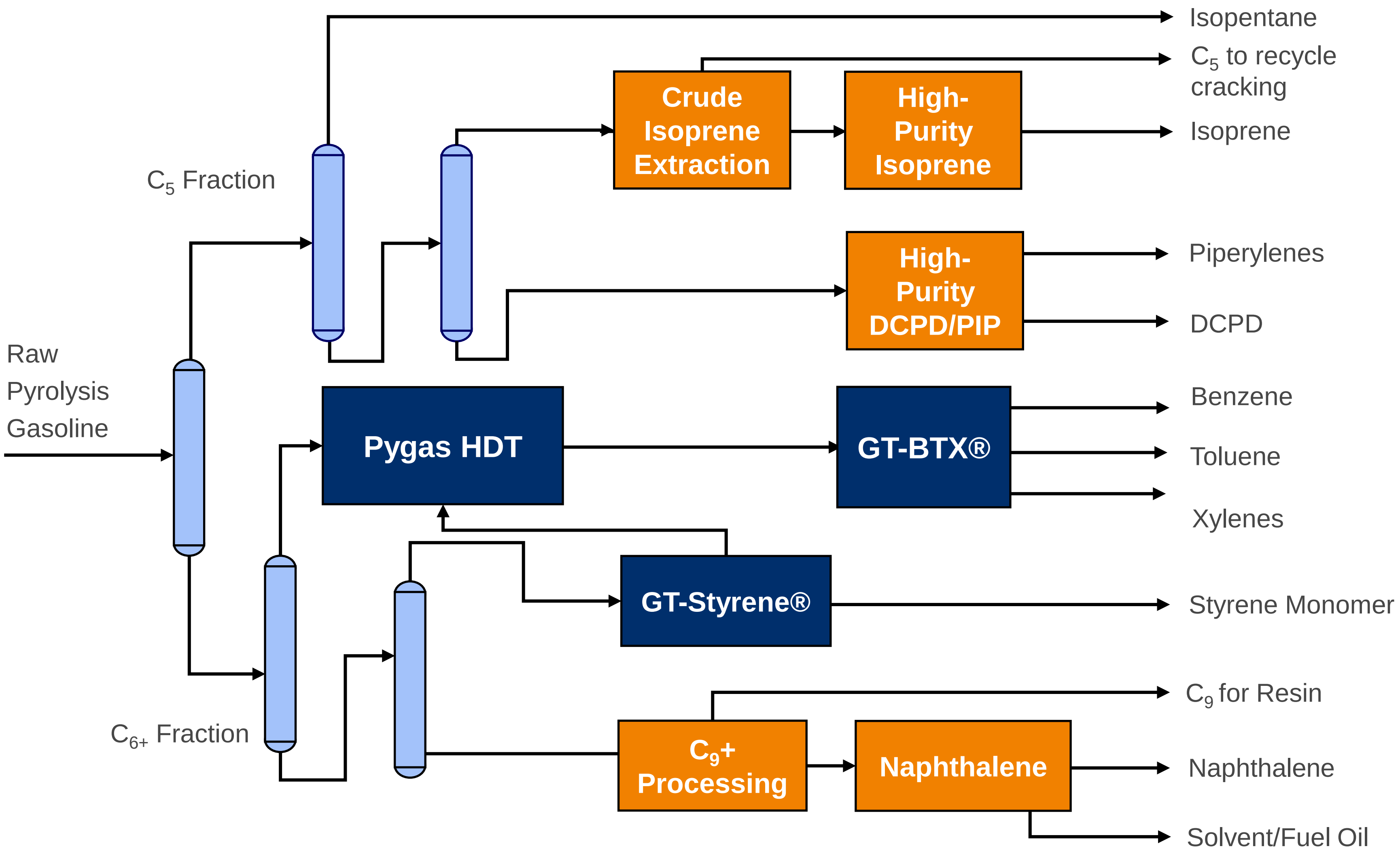
Process flow of C4 Reverse Isomerization



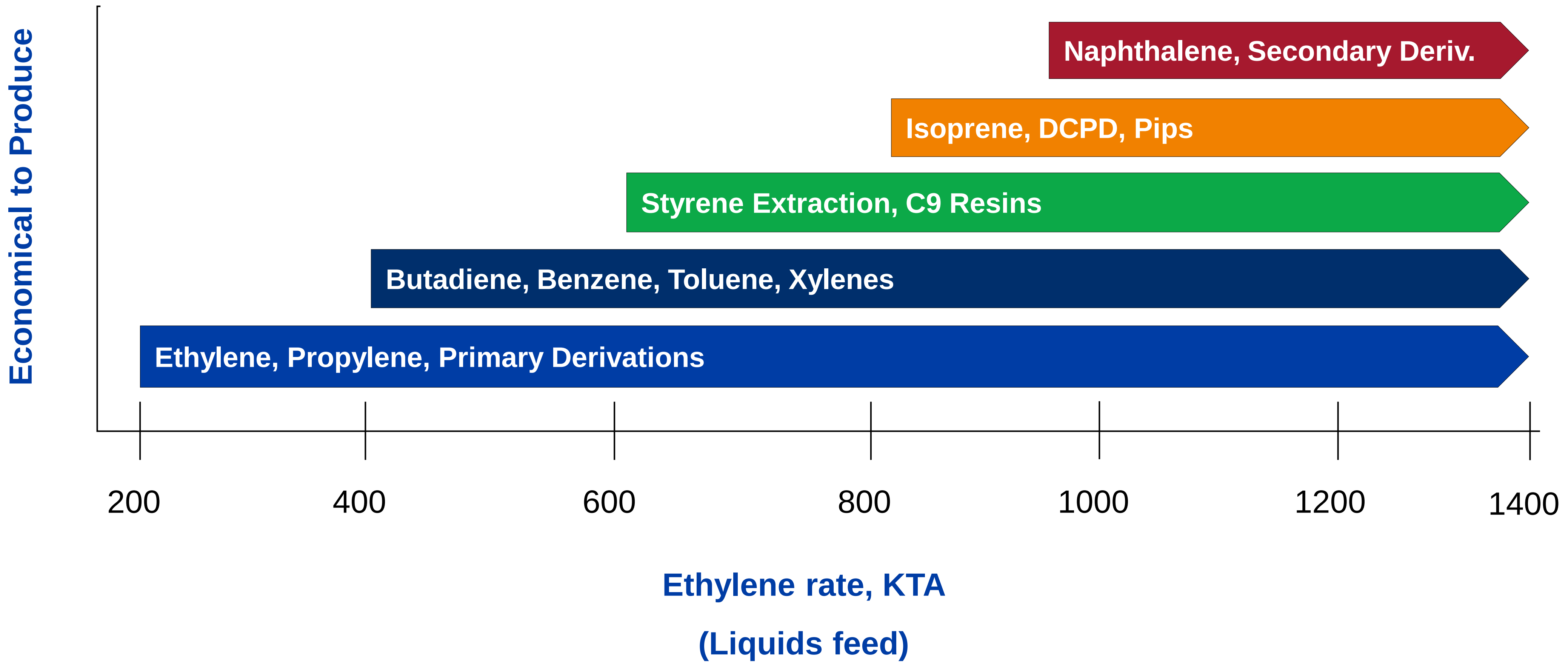
Expected Performance for iC5 Normalization

Catalyst service cycle, months	≥ 24
Catalyst service life, years	≥ 8
Selectivity, product yield per i-C5 in feed, wt. %	95-96
i-C5 "once-through" conversion, wt. %	35-40

Naphtha Cracker Byproducts – **Pygas**



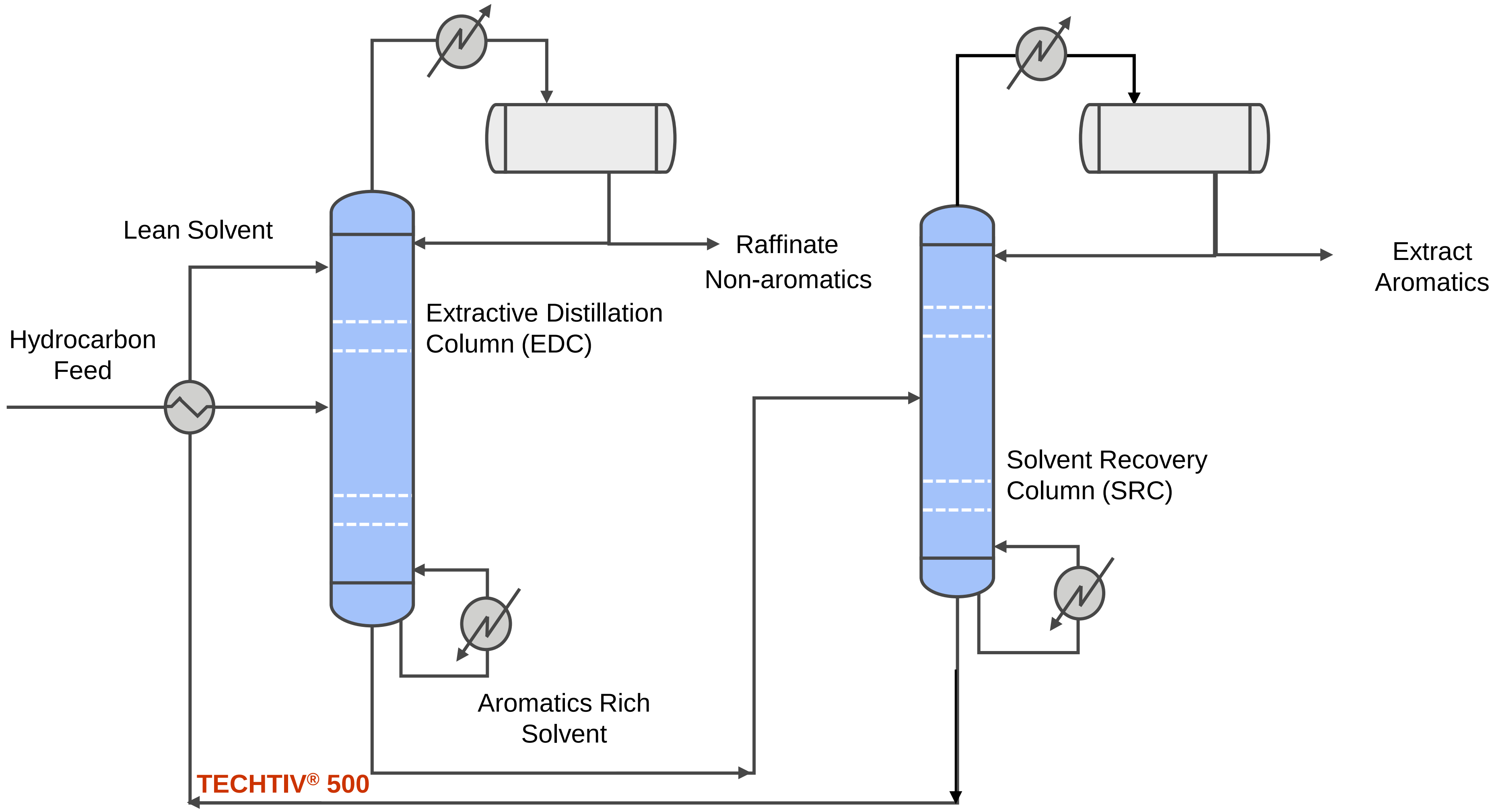
Economical Ethylene Capacity for Recovering By-products



Pygas Upgrading

Aromatics Extraction

GT-BTX® - General Flow Scheme



Extractive Distillation scheme - Major equipment are 2 columns

Solvent is critical to efficient Aromatics Extraction

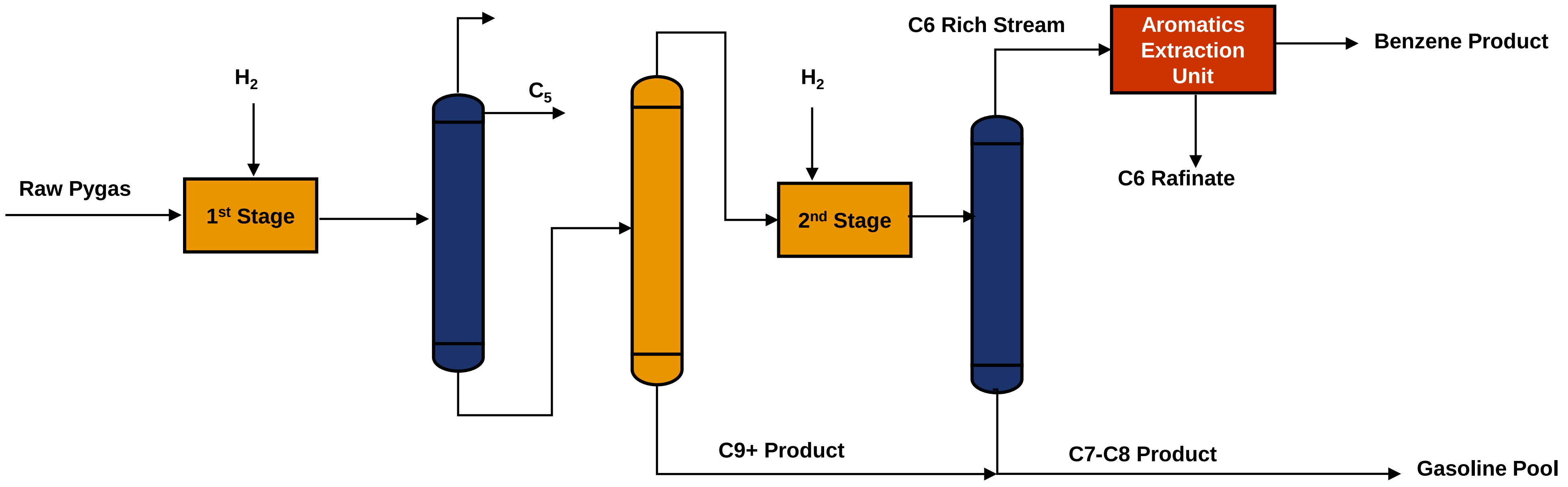
★ Solvent selectivity is critical

Proprietary Solvent of GT-BTX®
Technology

Solvent	α n-C_7/Benzene
Techtiv®-500	2.44
Sulfolane	2.00
N-methyl Pyrolidone	1.95
N-formyl morpholine	1.89
Glycol blends	1.35
None	0.57

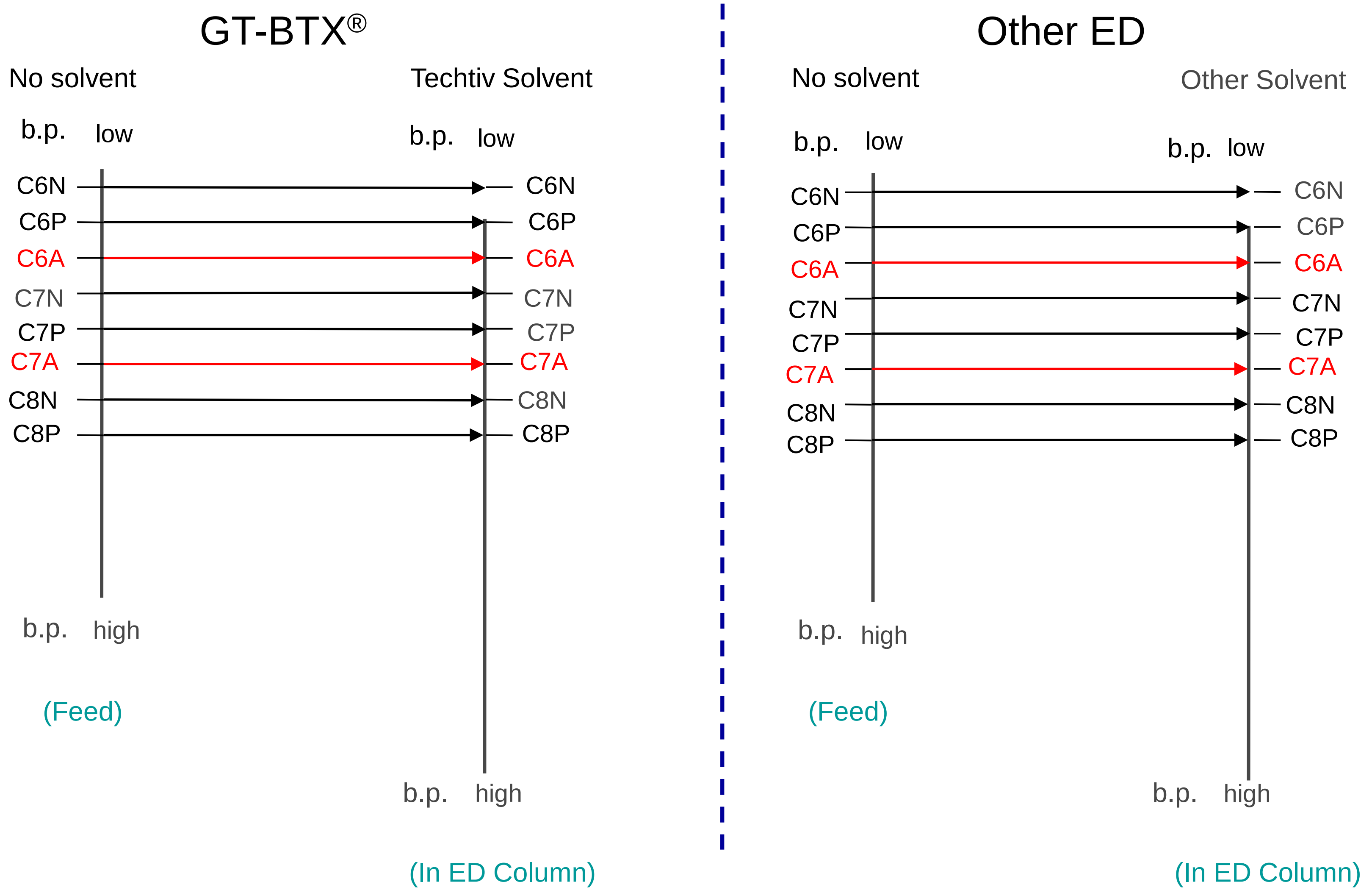
Extractive Distillation depends on a selective solvent to alter the boiling points of aromatics & non-aromatics to facilitate their separation by distillation.

Typical Pygas Processing with Benzene Only Recovery



- Two Stage Hydrogenation for diolefin/olefin saturation and sulfur removal
- C5 and C6 raffinate product recycle to cracker
- Benzene Product, C7-C8 cut and C9+ stream as Gasoline Blending Product

Different Solvent Systems in ED process for Aromatics Recovery ("BT" Extraction)



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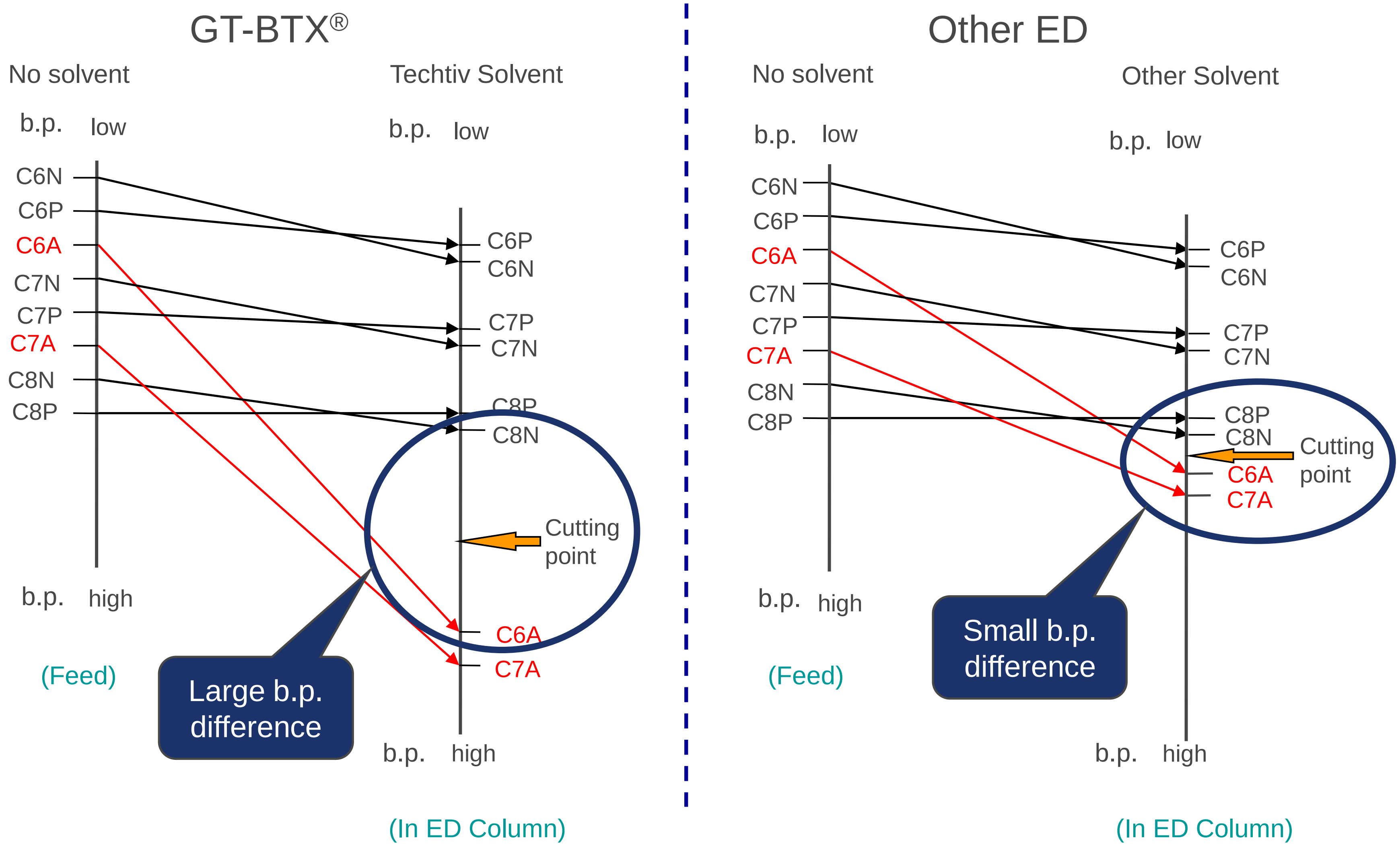
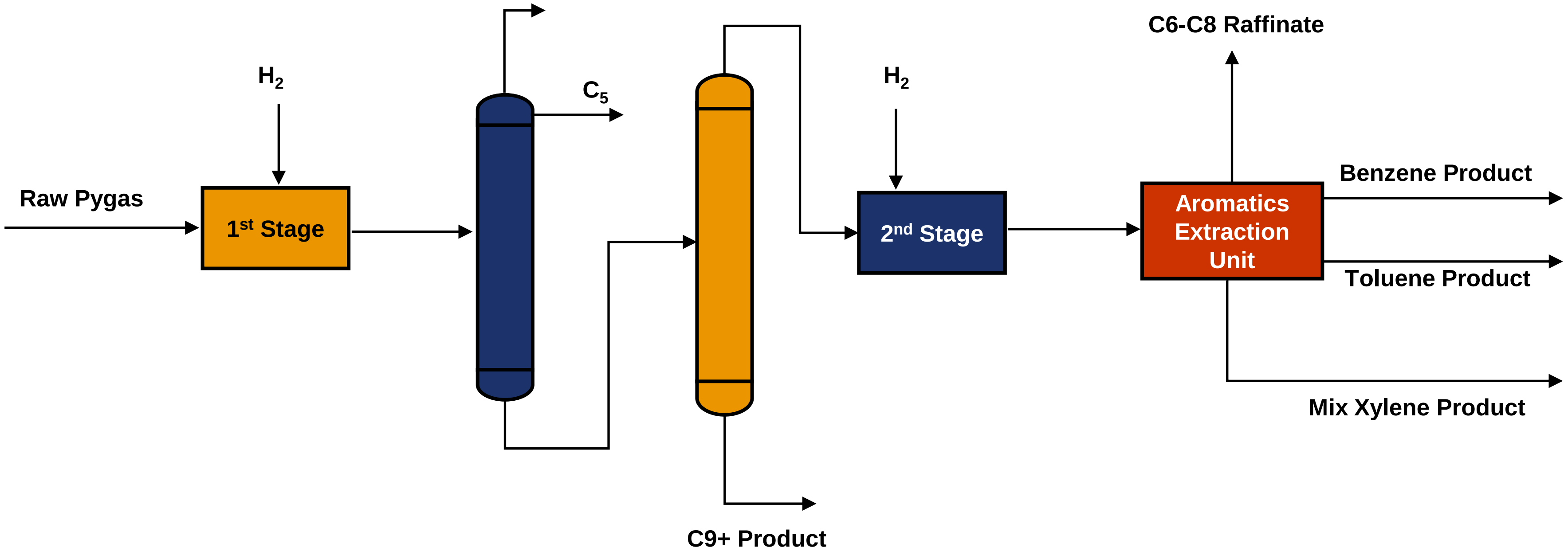


Typical Pygas Processing with Benzene, Toluene and Xylene Recovery



- Two Stage Hydrogenation for diolefin/olefin saturation and sulfur removal
- C5 and C6-C8 raffinate product recycle to cracker
- Benzene, Toluene and Mixed Xylenes Product

Experience in Pygas: 2 or 3 molecules Extraction

Company	Location	Feed Category	Scope	Start-up Status
Licensee 1	Saudi Arabia	Pygas C6-C8	Grassroots	2010
Licensee 2	China	Pygas C6-C8	Grassroots	2009
Licensee 4	Thailand	Pygas C6-C8	Grassroots	2010
Licensee 5	Taiwan	Pygas C6-C8	Grassroots	2013
Licensee 6	Saudi Arabia	Pygas C6-C7	Grassroots	2017
Licensee 7	China	Pygas C6-C7	Grassroots	2012
Licensee 8	Malaysia	Pygas C6-C7	Grassroots	2018
Licensee 10	Philippines	Pygas C6 - C7	Grassroots	Expected 2020
Licensee 11	China	Pygas C6-C8	Grassroots	BEP (2018)
Licensee 12	Indonesia	Pygas C6-C9	Grassroots	BEP (2019)
Licensee 13	Russia	Pygas C6	Grassroots	BEP (2019)
Licensee 14	Saudi Arabia	Pygas C6-C7	Grassroots	BEP (2020)
Licensee 15	Korea	Pygas C6-C7	Grassroots	BEP (2020)

- Benzene Purity > 99.95 wt%
- Toluene Purity > 99.8 wt%
- Aromatics Recovery > 99 wt%
- Specific Energy Consumption < 200 Kcal/kg

Styrene Monomer Recovery

Styrene Production Methods and Costs

Styrene Source	Global Capacity	Cost to Produce*
EB-Dehydrogenation EBSM	~80-85%	~795 € /ton
POSM	~10-15%	~655 € /ton
Extraction from Pygas	~2% +	**~555** € /ton

*Wood MacKenzie Chemicals “Petrochemical Markets in a Turbulent World” April 4, 2020

GT-Styrene20®: Styrene Monomer from Pygas

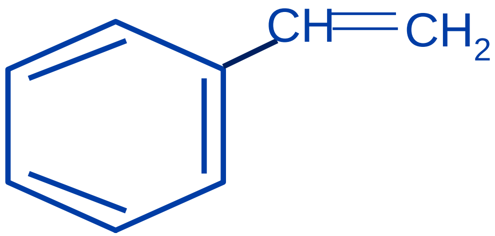
- For a steam cracker producing 800,000 Tons per year of ethylene from liquid feed components, there is potential to recover up to 25,000 TPY of Styrene Monomer.

- Historically, styrene recovery from pygas was not considered because the right technology was not available and ethylene crackers were not large enough for recovering styrene at economic scale.

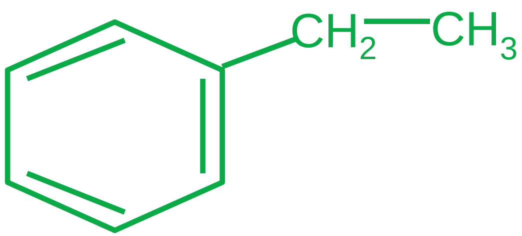
- Starting from last decade, capacity of ethylene cracker has become bigger and bigger, especially for the ones which are integrated with the refinery as many streams from refinery (such as LPGs, naphtha and gas oil) could be optimized as feed to cracker for pushing the olefins production capacity higher.

Styrene and Close-boiling Pygas Components

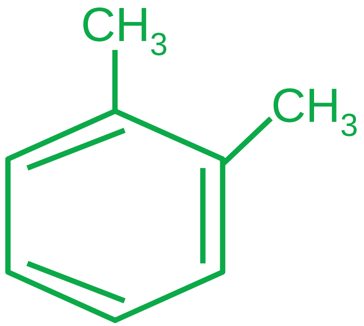
Pygas contains
- Paraffins
- Olefins
- Diolefins
- Aromatics
- Aromatic olefins



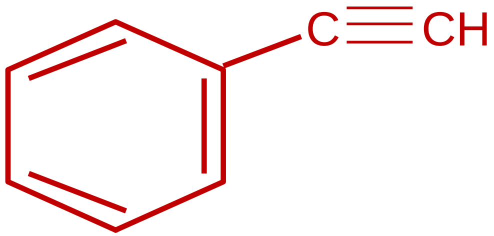
Styrene
NBP 145^{o}C



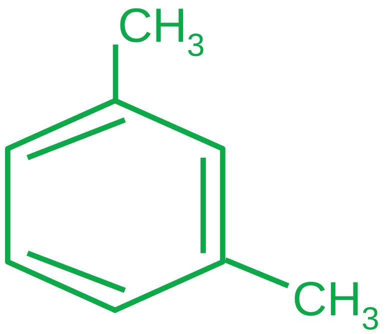
Ethylbenzene
NBP 136^{o}C



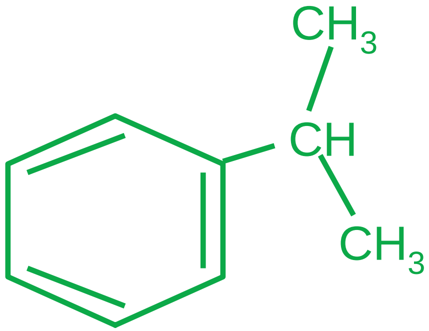
Orthoxylene
NBP 144^{o}C



Phenyl Acetylene
NBP 142^{o}C



Metaxylene
NBP 139^{o}C



Cumene
NBP 152^{o}C

Separation between Styrene and Close-boiling Components

Component	NBP (º C)	Relative Volatility to Styrene	Relative Volatility to Styrene (Enhanced)
Styrene	145	-	-
Ethylbenzene	136	1.3	2.6
Ortho-xylene	144	1.0	1.8
DCPD	152	0.6	1.4

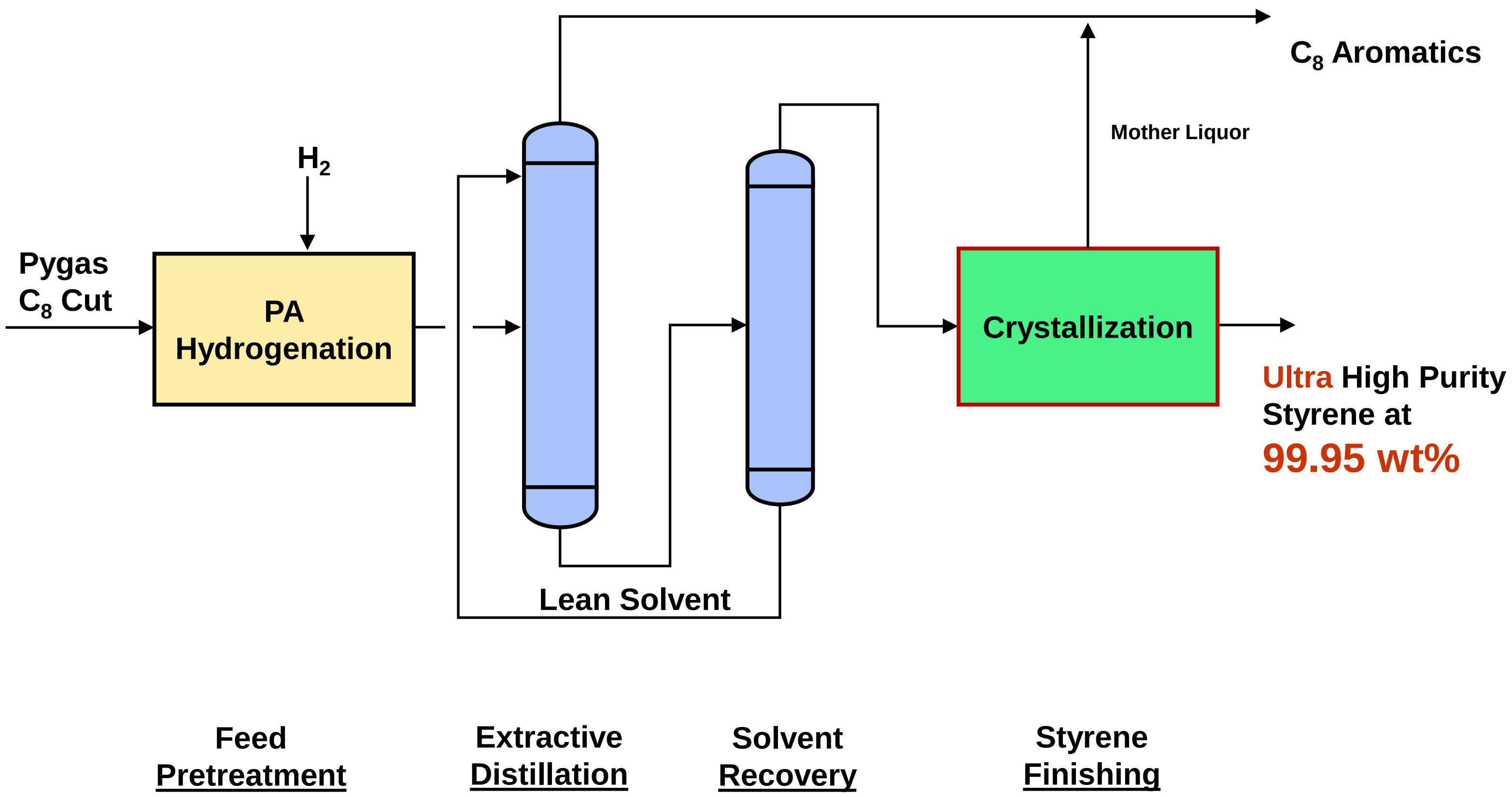
- Solvent-based system to extract and purify styrene
- Extractive distillation alters boiling points of components
- Through intensive research & process development, Sulzer GTC has designed an optimum solvent blend, Techtiv-200®

Styrene Monomer ASTM Specifications

Styrene Monomer product meets the general standard specification for Styrene ASTM D2827-13 as follows:

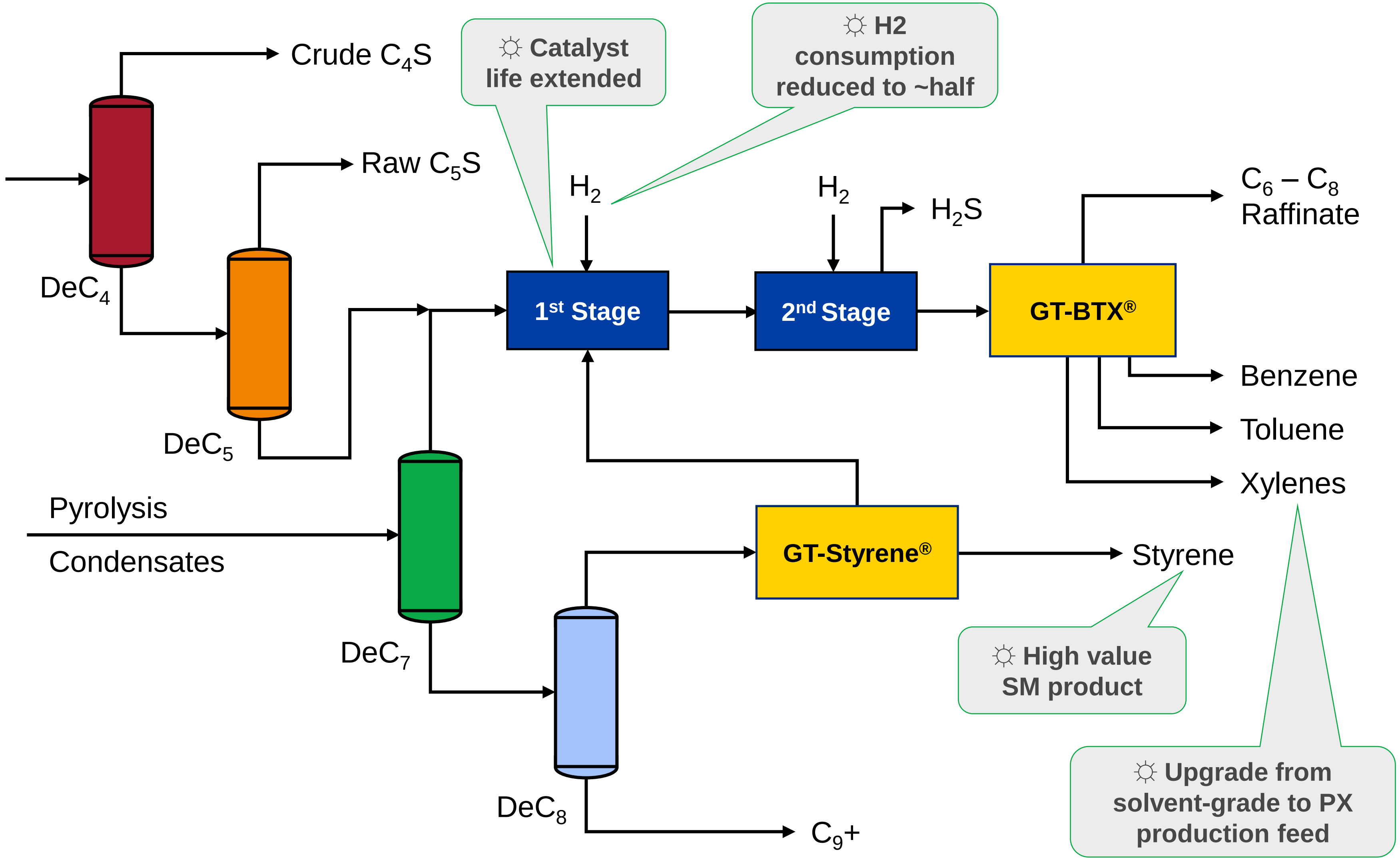
Property	Unit	Specification	ASTM Test Method
Color	Pt/Co scale	15 max	D5386
Styrene purity	wt%	99.8 min	D5135 or D7504
Aldehydes (as benzaldehyde)	wt%	0.01 max	D2119 or D7704
Peroxides (as H_2O_2)	mg/kg	50 max	D2340
Polymer	mg/kg	10 max	D2121, Test Method A
Inhibitor	mg/kg	10-15	D4590
Ethylbenzene	mg/kg	500 max	D5135 or D7504
Benzene	mg/kg	1 max	D6229
Appearance		Clear liquid free of sediment and haze at 65 (18 ^{0}C) to 78^{o}F (25 ^{0}C)	

GT-Styrene®20: 2nd Generation and Current Styrene Extraction Process

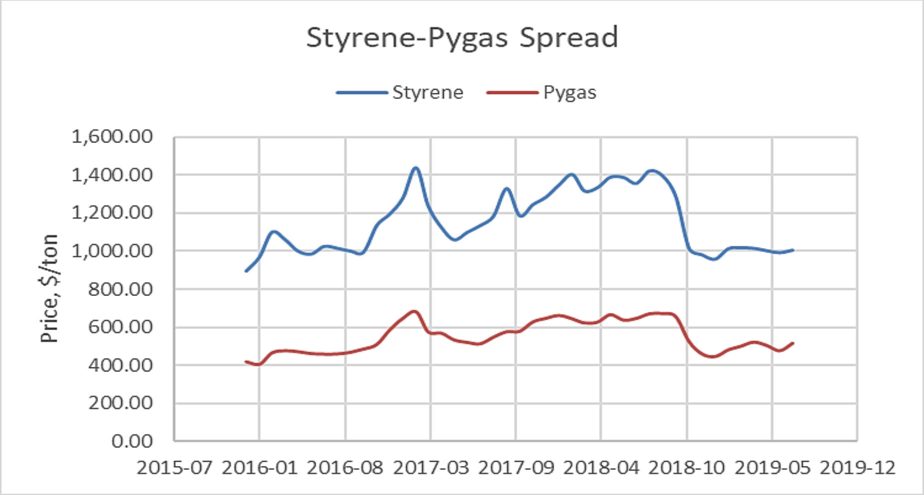


- New approach for final purification of the Styrene
- One Step Crystallization vs. multi-step processing
- The crystallization makes Ultra high purity product, meeting all of the specifications.
- Nominal purity is on the order of >99.95%.
- Total Sulfur < 5 wppm

GT-Styrene20: Improved Pygas Processing



GT-Styrene®: Benefits



	Before GT-Styrene®	After GT-Styrene®
RIT/ROT for 1st stage reactor, °C	55/102	62/85
RIP/ROP for 1st stage reactor, kg/cm^{2}G	27/26.2	27/26.5
Recycle/Fresh ratio for 1st stage reactor	2.8	2.3
H2 consumption over feed, kg per ton	10	6.5
Catalyst regen cycle, years	2	4
Catalyst life, years	4	7

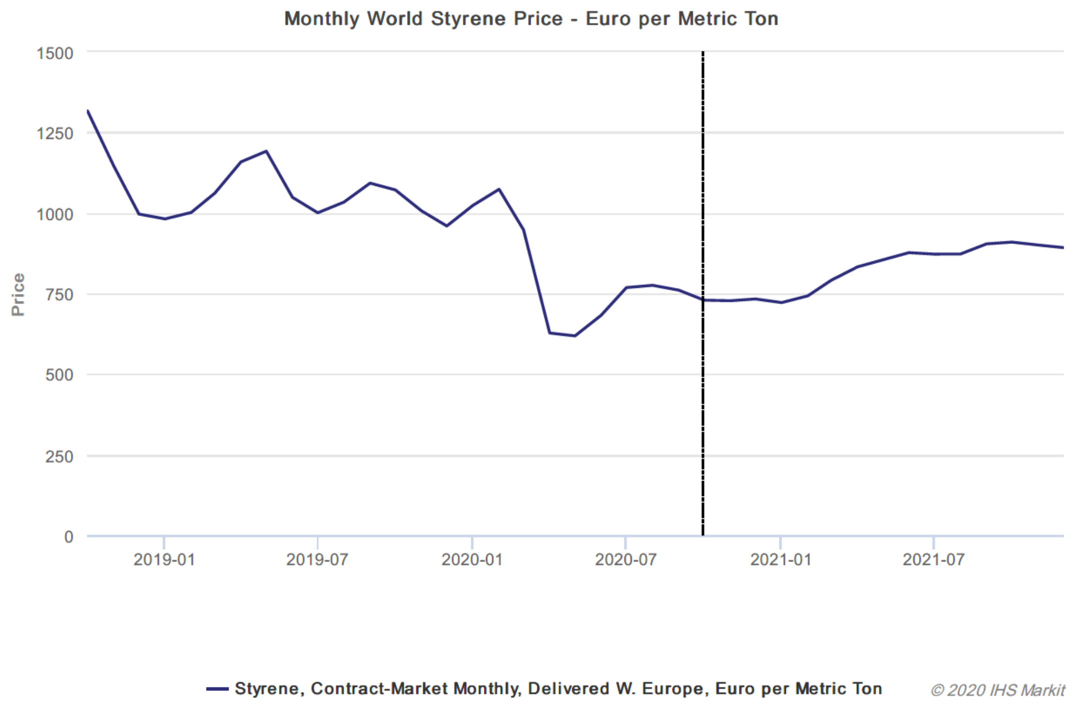
- Economic: Styrene – Pygas Spread, Xylene upgrade
- Operational: Improved Pygas HDT operation and opex

GT-Styrene20®: Typical Economics

Basis: 25,000 tpa styrene

Typical USGC grassroots capital cost (ISBL)	$30 million
Styrene Production Cost	$600/ton
Styrene product sales value	$1000/ton
Net profit	$10 million/yr
Simple annual ROI	30%

- Existing HDT greatly debottlenecked for lower H2 consumption and longer catalyst life
- Additional value for xylenes upgrade

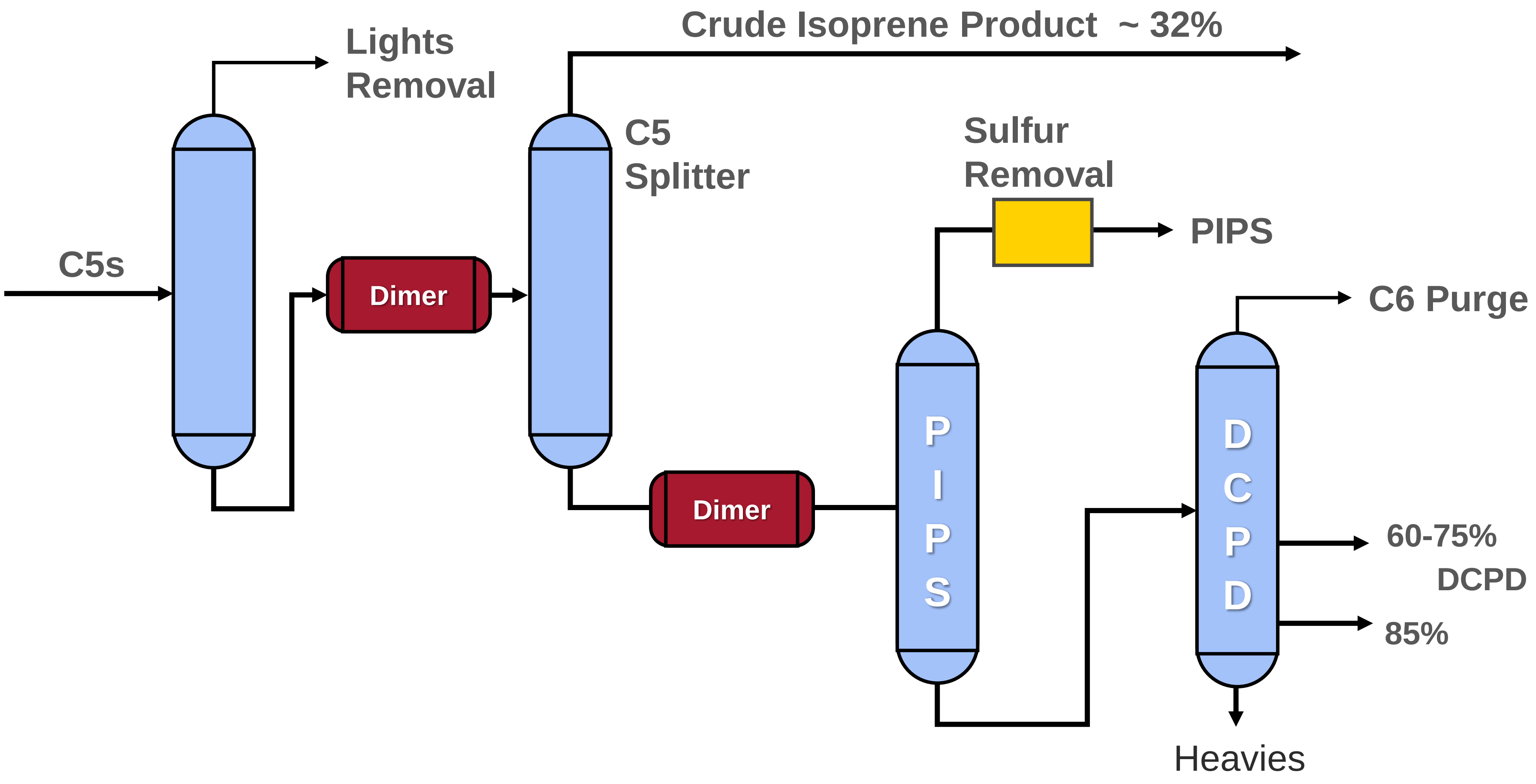


GT-Styrene®20: Keeping Naphtha Crackers Competitive

- GT-Styrene®20 technology - effective complement to world-scale naphtha or mixed feed crackers
- GT-Styrene® provides excellent value for steam crackers which produce more than 600,000 tpa ethylene, based on liquid feedstock or 1,200,000 tpa ethylene from a typical mixed feedstock
- Reduced-EB xylenes available as co-product of GT-Styrene® 20
- **7 licensed units, 3 in operation for more than 5 years**
- **4th licensed unit (84 KTA – largest) will be in operation Q4 2021 in ZPC complex China**
- **2nd gen Styrene License award in Europe in Q3 2020**

DCPD Production

Pygas C5 Utilization – GT-C5



GT-C5: DCPD Production

Product Quality

DCPD: ~85 wt%

Benzene: <0.1 wt%

Total Lights (C6- excluding CPD): <0.5 wt%

Codimers+Trimers: ~14 wt%

Equipment	Count
Column	4
Drum	4
Reactor (Dimer Drum)	1
Heat Exchanger	12
Pump	9
TIC (2020 USGC Basis)	8.7 MM$

Thank You!

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