Steam Cracker Design and Operation Considerations to Enhance Feed Flexibility

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Lovraj Kumar Memorial Trust Workshop

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Agenda

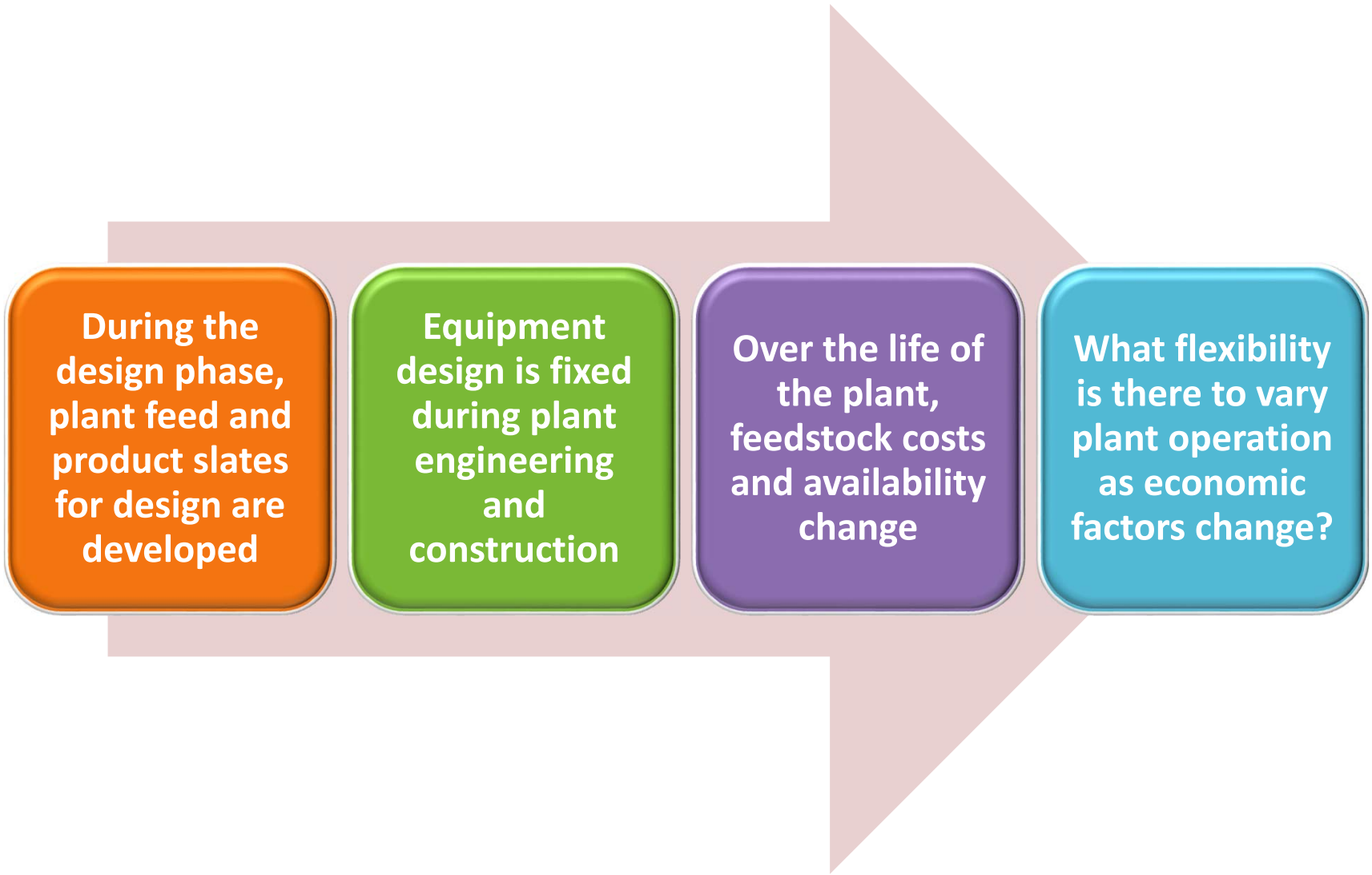
- Steam Crackers Feedstock Fiscal Dynamics
- Impact of Varying Feedstock on Naphtha Cracker
- Case Study: Adding Naphtha Flexibility to an Ethane Cracker
- Increase Ethane Cracker Capacity by Varying Heater Operation
- Summary



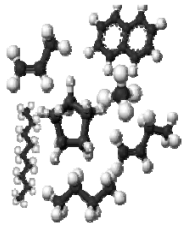



Steam Crackers Feedstock Fiscal Dynamics

Changing Feedstock



Challenges of Feedstock Changes



By-product rates

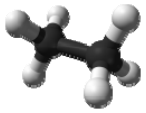
Cracking heater operation and capacity

Recovery section operation and capacity

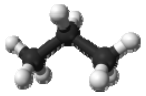
Impact of Varying Feedstock on Naphtha Cracker

Typical 1000 kta Plant

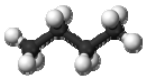
Light Naphtha Cracker



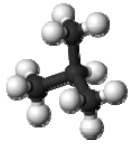
Produce 1/3 of ethylene from ethane – 2 heaters



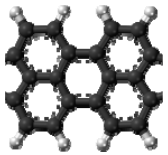
Produce 1/3 of ethylene from propane – 2 heaters



Produce 1/3 of ethylene from n-butane – 2 heaters



Produce 1/3 of ethylene from i-butane – 2 heaters



Produce 1/6 of ethylene from gas oil – 1 heater

Ethane **$170/ton (US)** **$340/ton (Other)**	**Propane** **$309/ton (US)** **$605/ton (Other)**	**Butanes** **$340/ton (US)** **$415/ton (Other)**
Naphtha **$590/ton**	**Gas Oil** **$530/ton**	**Ethylene** **$965/ton (US)** **$1270/ton (Other)**
Propylene **$1145/ton (US)** **$1070/ton (Other)**	**Butadiene** **$1090/ton**	**Benzene** **$875/ton**

Material Balances – Constant Ethylene Production

	Naphtha Only	Naphtha + Ethane	Naphtha + Propane	Naphtha + n-Butane	Naphtha + i-Butane	Naphtha + Gas Oil
Naphtha	2.77	2.03	2.03	1.86	1.82	2.29
Other Feed	0.00	0.34	0.61	0.77	2.01	0.63
Ethylene	1.00	1.00	1.00	1.00	1.00	1.00
Propylene	0.43	0.32	0.40	0.41	0.72	0.46
Butadiene	0.15	0.12	0.13	0.13	0.15	0.16
Benzene	0.21	0.16	0.18	0.16	0.22	0.20
Gross Margin USGC	100%	121%	125%	128%	181%	104%
Gross Margin Other	100%	103%	97%	110%	141%	103%

Material Balances – Constant Ethylene Production

	Naphtha Only	Naphtha	Naphtha	Naphtha +	Naphtha + i-Butane	Naphtha + Gas Oil
Naphtha	2.77				1.82	2.29
Other Feed	0.00				2.01	0.63
Ethylene	1.00				1.00	1.00
Propylene	0.43				0.72	0.46
Butadiene	0.15				0.15	0.16
Benzene	0.21				0.22	0.20
Gross Margin USGC	100%				181%	104%
Gross Margin Other	100%	103%	97%	110%	141%	103%

What capacity is possible with alternative feeds?

If ethylene capacity can be maintained then all alternative feedstocks are economically attractive

Impact of Varying Feedstock on Plant Operation

- New control valves required
- Feed preheat bypass required
- Ethylene production capacity increases
- Ethane recycle doubles, vaporization system modifications required

- Charge gas compressor molecular weight decreases, higher speed required

Adding Ethane

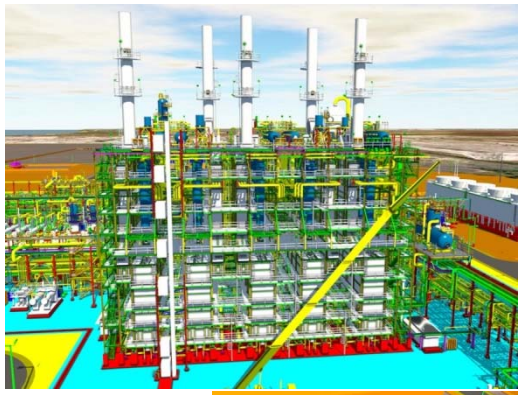
- **Ethylene fractionator load increases 7%**
- Propylene refrigeration load increases 3%
- Hydrogen flow increases 40%

Ethane cracking is possible with minor modifications
Capacity will be reduced

Impact of Varying Feedstock on Plant Operation

Adding Propane

- New control valves required
- Feed preheat bypass required
- Ethylene production capacity increases
- Propane recycle triples, vaporization system modifications required
  - Charge gas compressor load increases 3%
- Methane offgas flow increases 8%
- **Coldest level refrigeration requirement increases 8%**



Propane cracking is possible with minor modifications
Capacity will be reduced

Material Balances – Prorated for Capacity Limits

	Naphtha Only	Naphtha + Ethane	Naphtha + Propane	Naphtha + n-Butane	Naphtha + i-Butane	Naphtha + Gas Oil
Naphtha	2.77	1.90	1.88	1.81	0.91	2.08
Other Feed	0.00	0.31	0.56	0.74	1.01	0.58
Ethylene	1.00	0.93	0.93	0.97	0.50	0.91
Propylene	0.43	0.30	0.37	0.40	0.36	0.42
Butadiene	0.15	0.11	0.12	0.13	0.08	0.15
Benzene	0.21	0.15	0.16	0.16	0.11	0.18
Gross Margin USGC	100%	113%	116%	124%	90%	95%
Gross Margin Other	100%	96%	90%	107%	71%	94%

When impact on plant capacity is considered, feedstock selection is dependent upon prices for feed, fuel, and products

Feed Flexibility Case Study

Adding Naphtha Flexibility to an Ethane Cracker

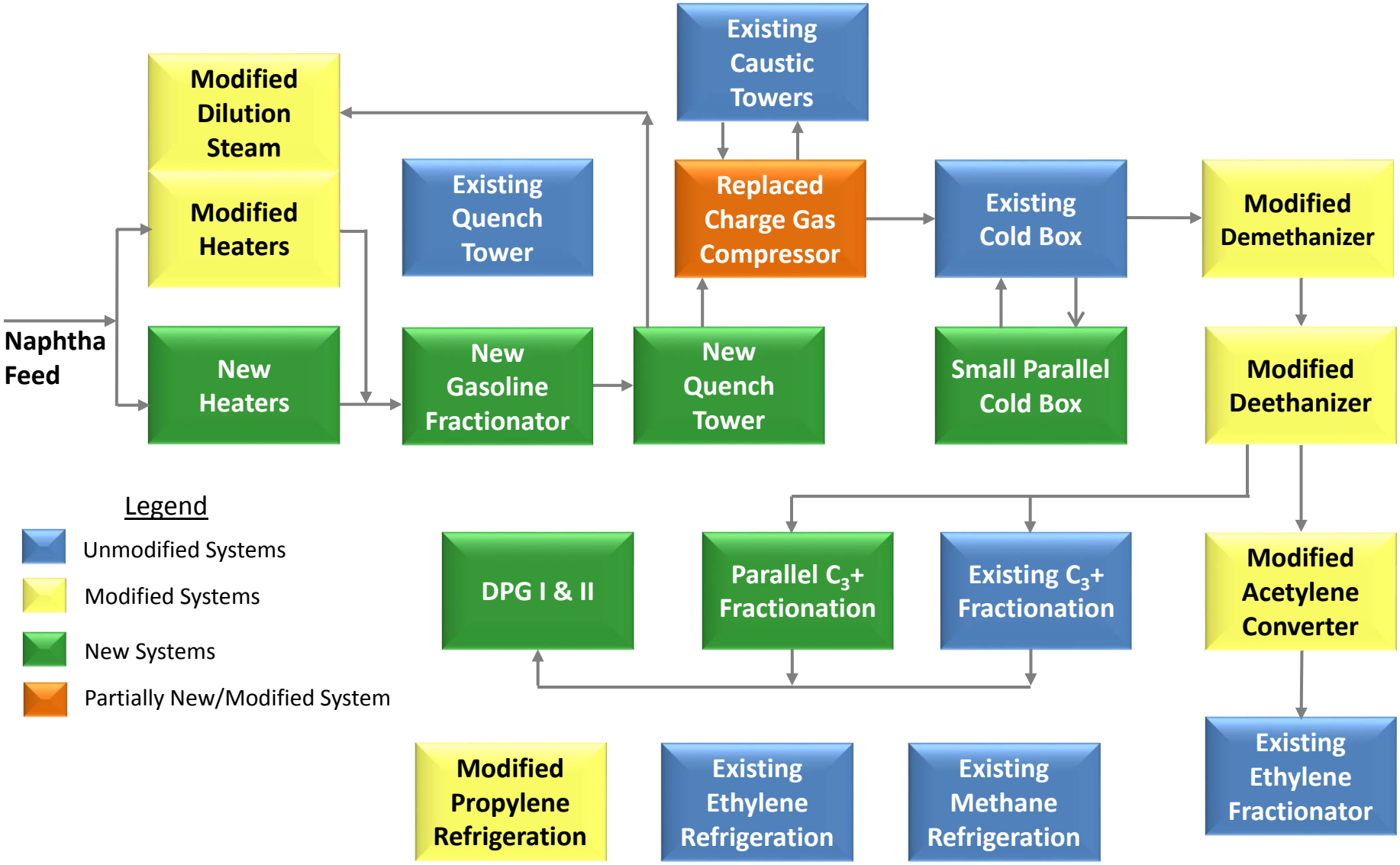
Adding Naphtha Flexibility to an Ethane Cracker

- Availability of ethane has dropped in some regions
  - Conversion of ethane crackers to naphtha crackers is being studied
- Case study definition
  - Ethane cracker studied was previously expanded twice
  - Convert to 100% naphtha cracker
  - Maintain ability to crack ethane
- Revamp viability judged in comparison to new grassroots plant designed to crack naphtha

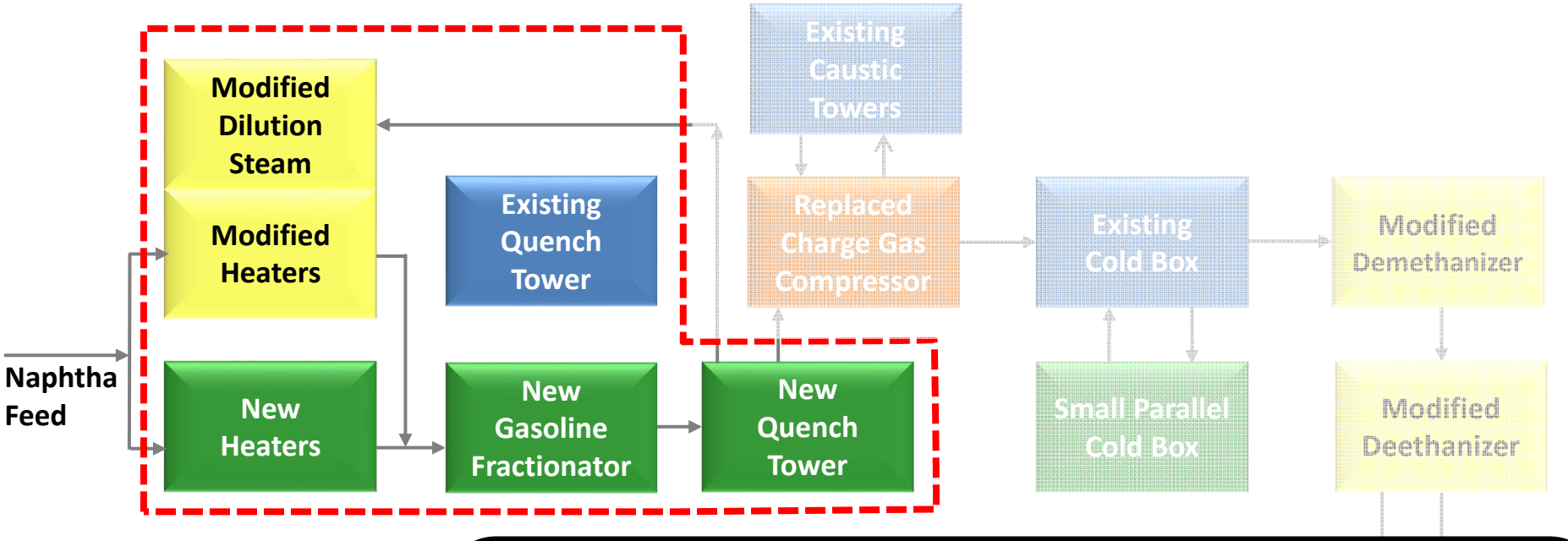
Material Balances

kta	Current Operation	Naphtha Only	Ethane Only
Ethane	635	0	661
Naphtha	0	1661	0
Other Feed	121	0	0
Ethylene	500	500	500
Propylene	37	264	16
Ethane Product	0	82	0
Propane Product	0	264	0
Mixed C_4 Product	39	168	23
C_5+ Product	44	0	26
C_6-C_8 Product	0	238	0

Adding Naphtha Flexibility to an Ethane Cracker



Adding Naphtha Flexibility to an Ethane Cracker



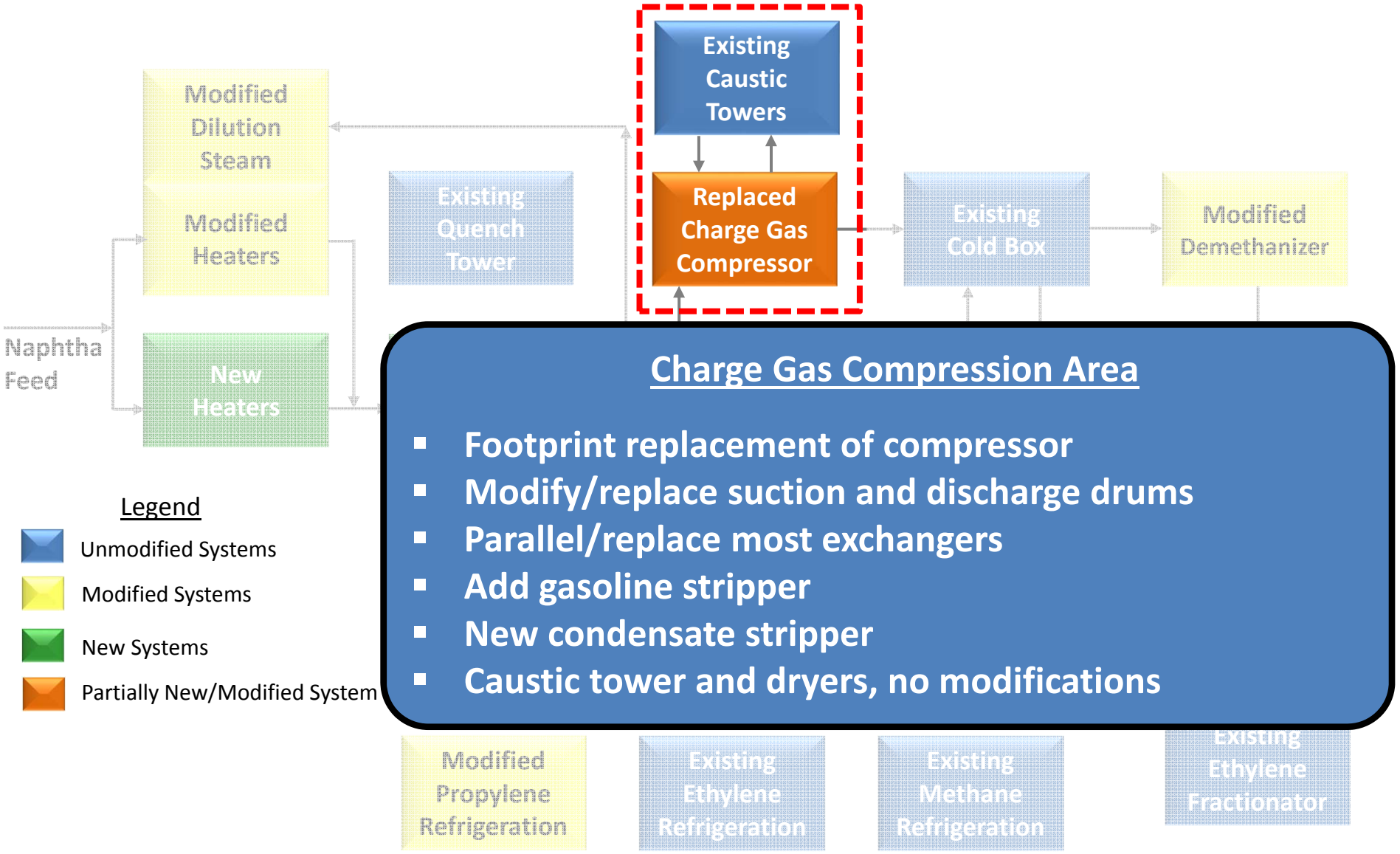
Legend

- Unmodified Systems
- Modified Systems
- New Systems
- Partially New/Modified System

Hot Section

- Extensive modifications to existing heaters
- Add 2 new heaters
- Add new hot fractionation equipment (gasoline fractionator and quench oil system, PFO stripper, process water stripper, quench tower)
- Modifications to dilution steam system

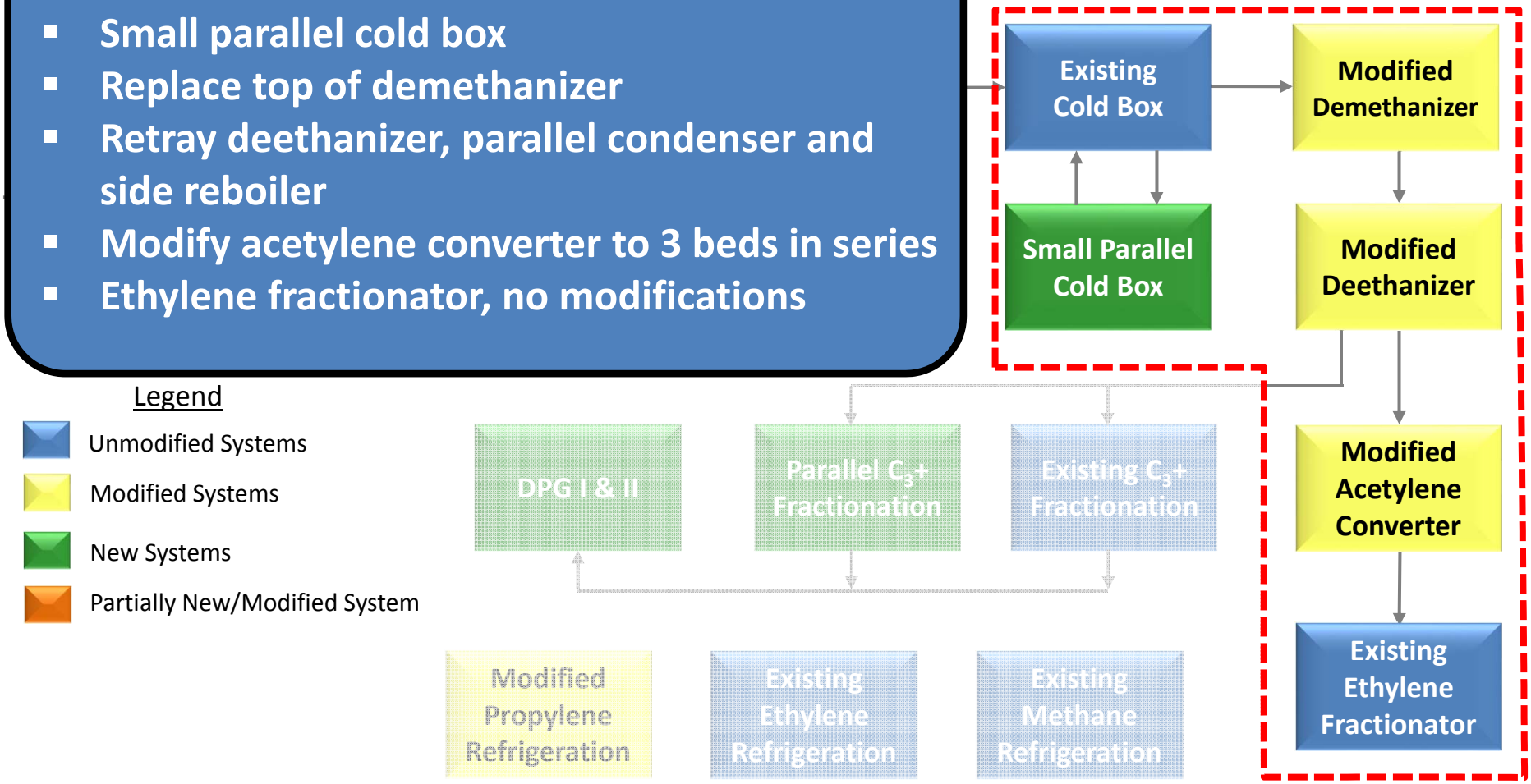
Adding Naphtha Flexibility to an Ethane Cracker



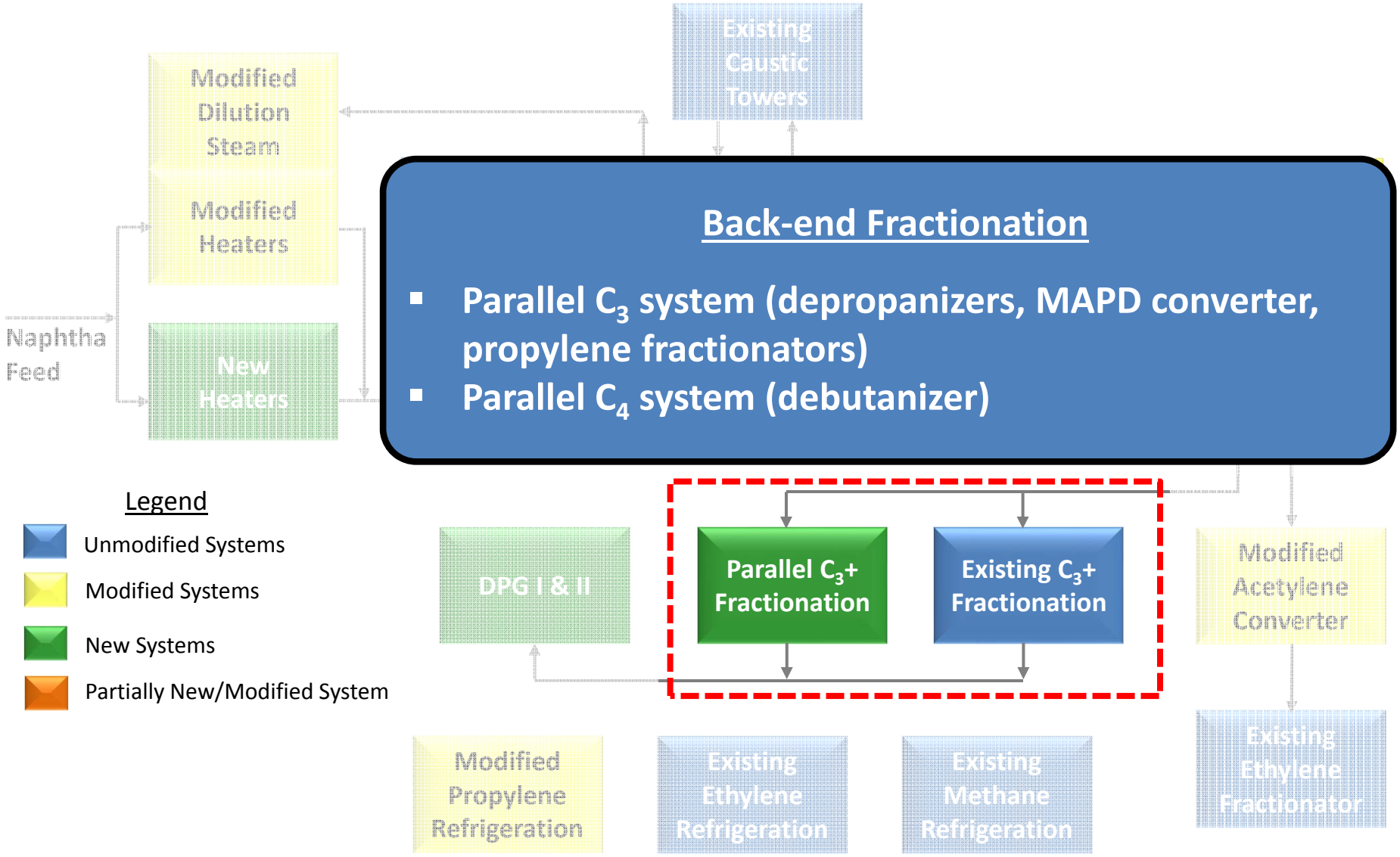
Adding Naphtha Flexibility to an Ethane Cracker

Chilling Train, Demethanizer, and C_2 Area

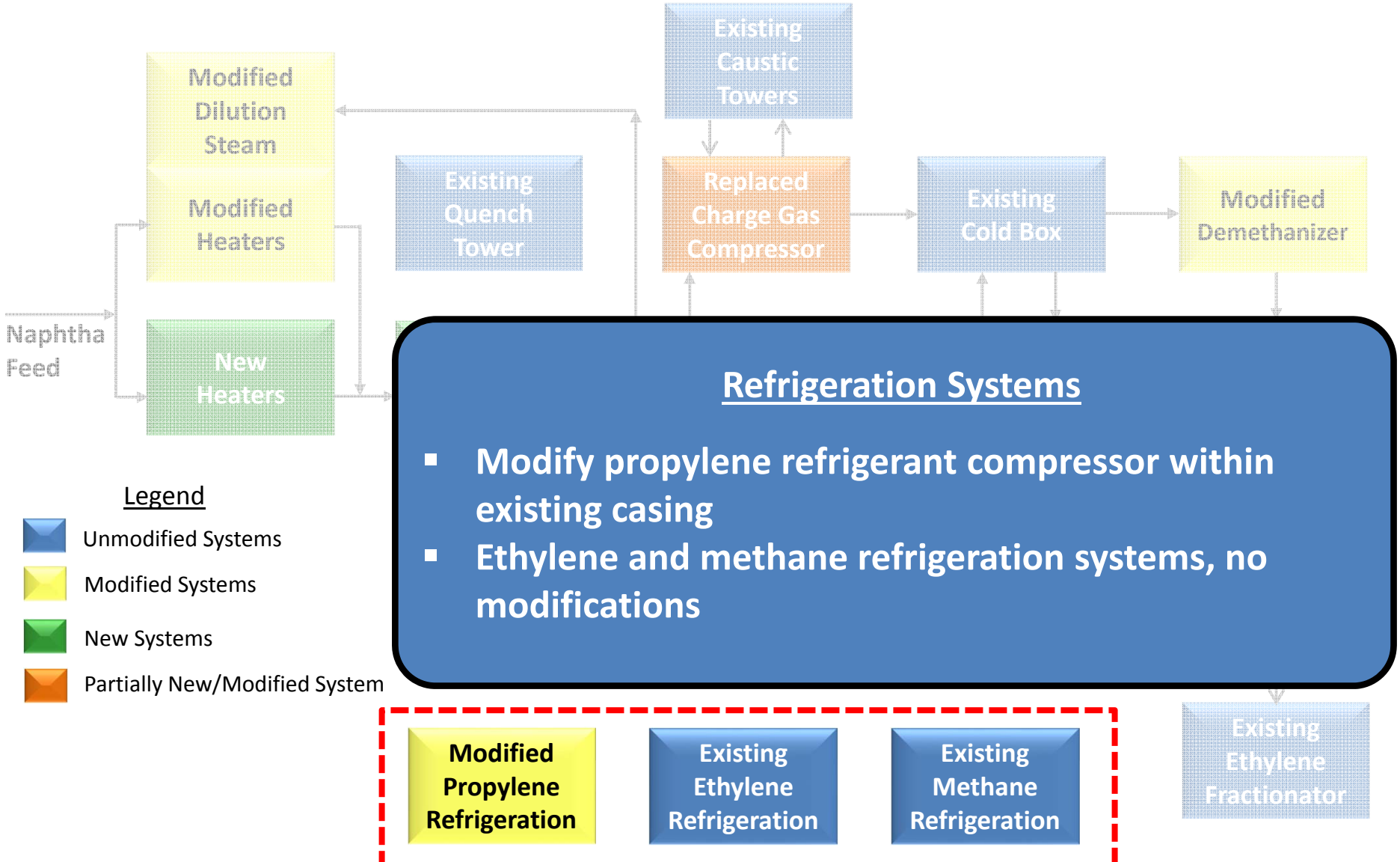
- Small parallel cold box
- Replace top of demethanizer
- Retray deethanizer, parallel condenser and side reboiler
- Modify acetylene converter to 3 beds in series
- Ethylene fractionator, no modifications



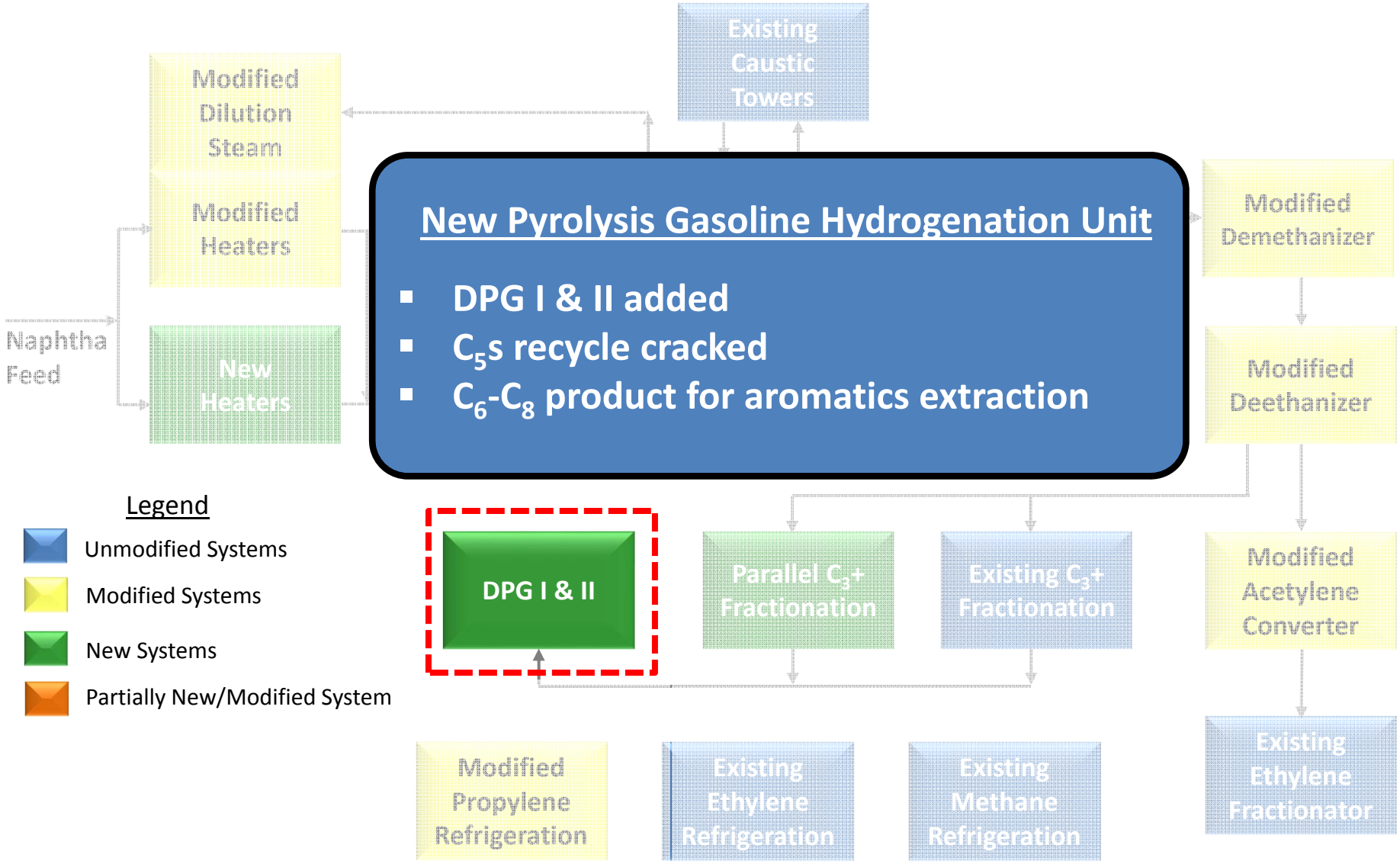
Adding Naphtha Flexibility to an Ethane Cracker



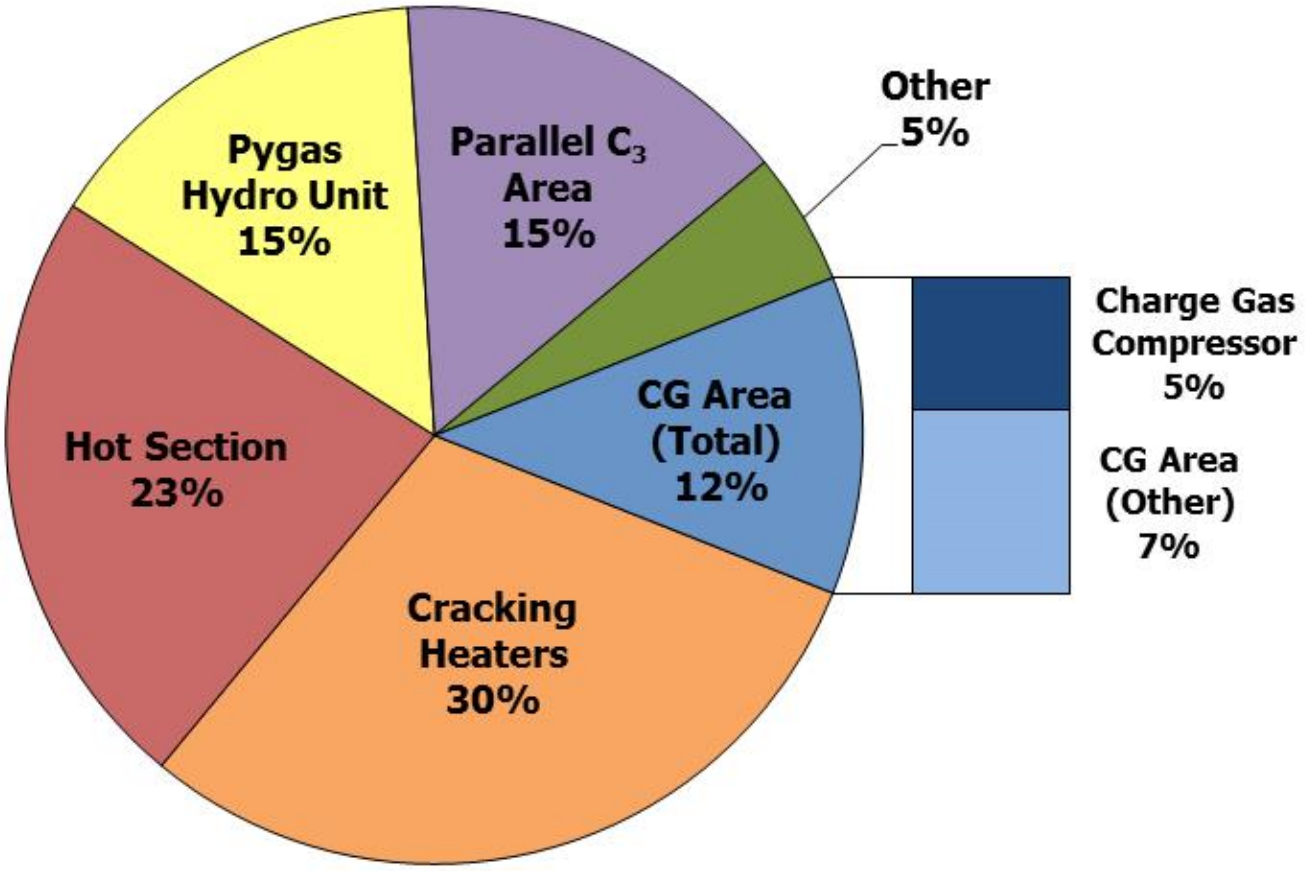
Adding Naphtha Flexibility to an Ethane Cracker



Adding Naphtha Flexibility to an Ethane Cracker



Breakdown of costs for adding naphtha flexibility



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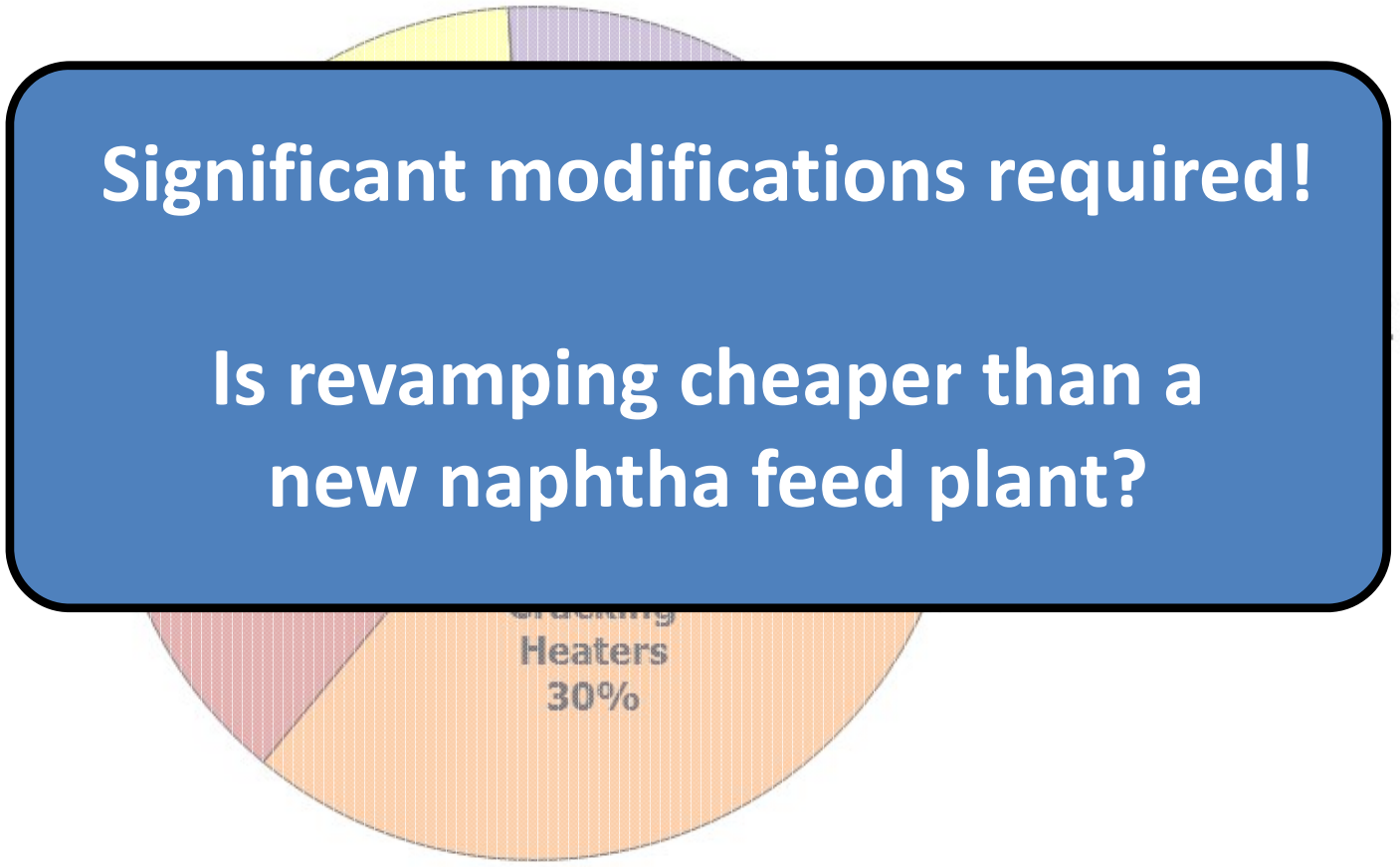
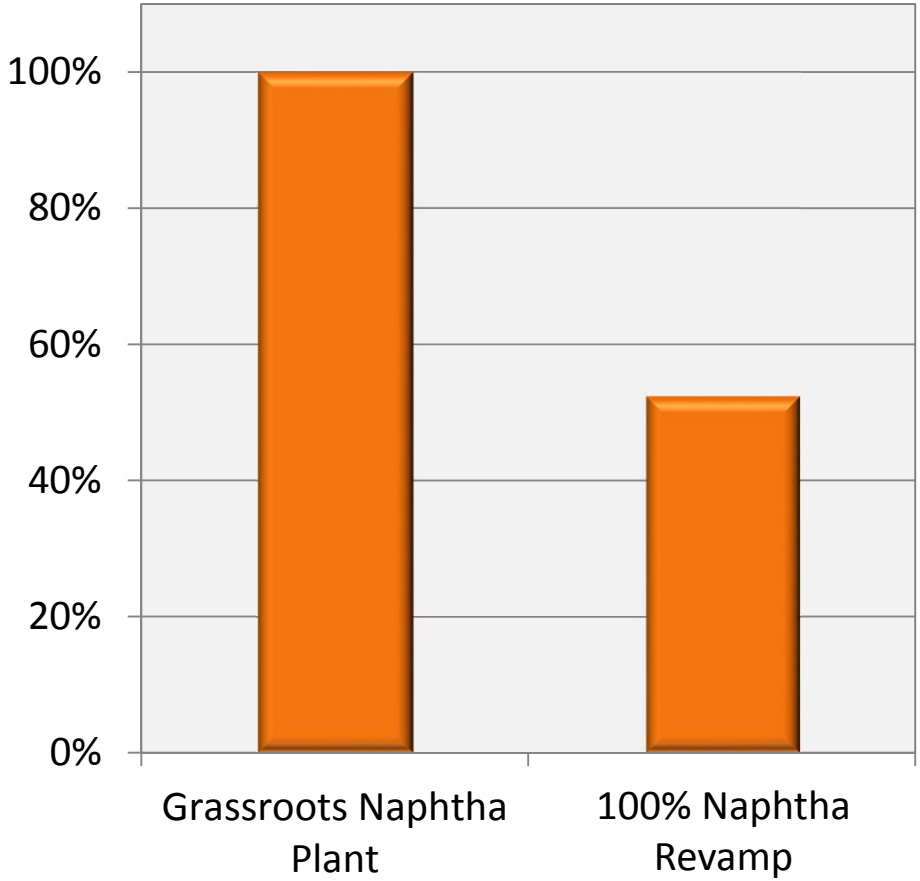


Significant modifications required!

Is revamping cheaper than a new naphtha feed plant?

Comparison of revamp cost to a new grassroots plant

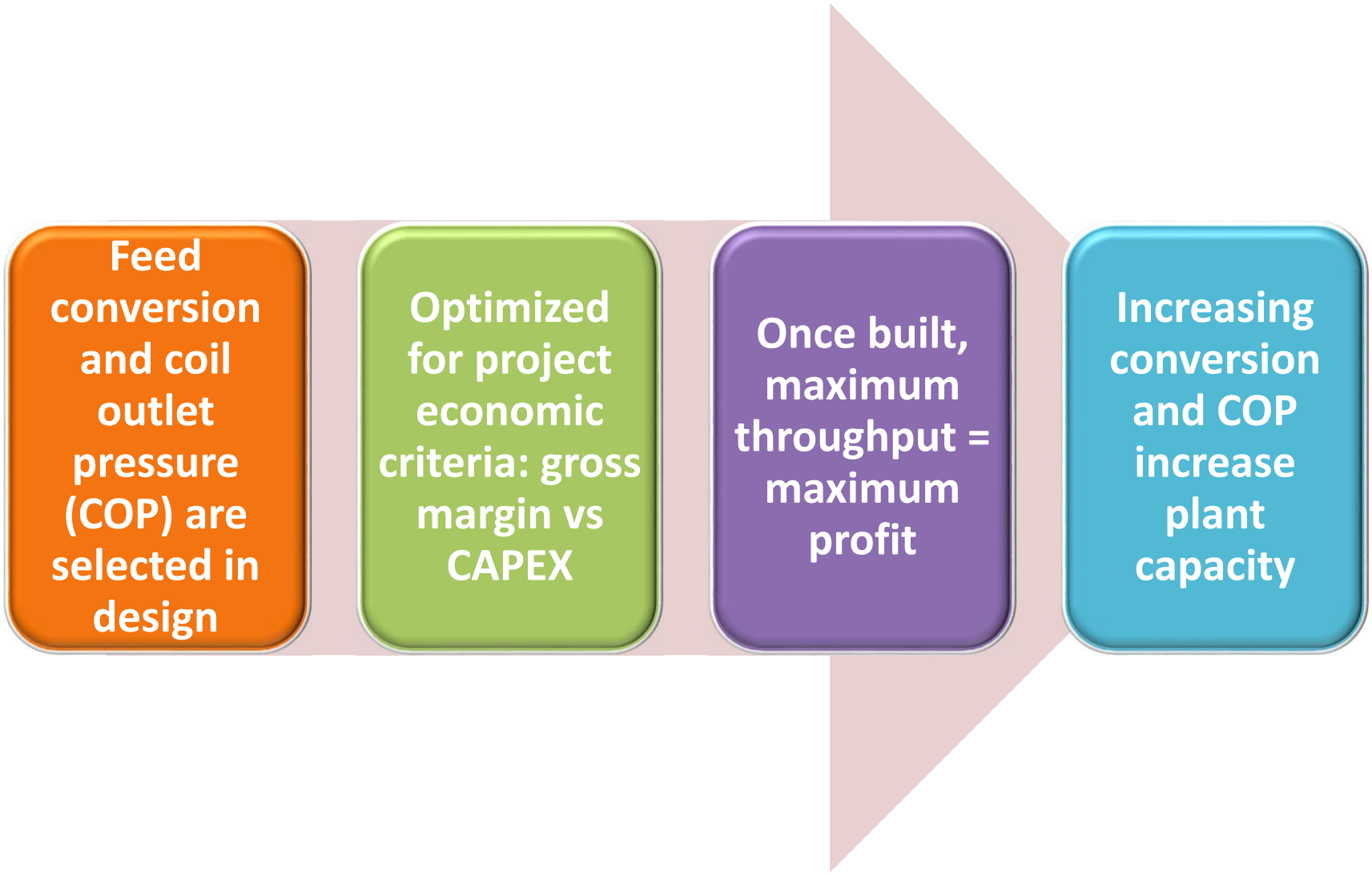


Breakpoints exist between no flexibility and 100% flexibility

Alternate levels of flexibility can be added for less cost than 100% flexibility

Increase Ethane Cracker Capacity by Varying Heater Operation

Ethane Cracker



Impact of Varying Heater Operation

Ethane	Conversion	Coil Outlet Pressure, kg/cm^2a (psia)	Steam-to-hydrocarbon Ratio
Base	65%	1.76 (25)	0.3
Increase Conversion	70%	1.76 (25)	0.3
Increase COP	65%	2.11 (30)	0.3
Increase Both	70%	2.11 (30)	0.3

Material Balances – Constant Ethylene Production

	Base	Increase Conversion	Increase COP	Increase Both
Ethane	1.27	1.31	1.29	1.33
Ethylene	1.00	1.00	1.00	1.00
Propylene	0.02	0.02	0.02	0.02
Butadiene	0.02	0.03	0.03	0.03
Benzene	0.01	0.01	0.01	0.02
Gross Margin USGC	100%	102%	101%	103%
Gross Margin Other	100%	102%	101%	102%

Even at constant ethylene production
more feed = more profit

Impact of Varying Heater Operation – Ethane Cracker

Heater capacity	102% of base	101% of base	101% of base
Heater run length	shorter than base		
Charge gas compressor load	**99% of base**	91% of base	90% of base
Ethylene fractionator load	94% of base	**101% of base**	**94% of base**
Binary refrigeration load	105% of base	102% of base	108% of base

Material Balances – Prorated for Capacity Limits

	Base	Increase Conversion	Increase COP	Increase Both
Ethane	1.27	1.32	1.28	1.42
Ethylene	1.00	1.01	0.99	1.06
Propylene	0.02	0.02	0.02	0.03
Butadiene	0.02	0.03	0.03	0.03
Benzene	0.01	0.01	0.01	0.02
Gross Margin USGC	100%	103%	100%	109%
Gross Margin Other	100%	103%	100%	109%

Increasing conversion and/or coil outlet pressure maximizes profitability

Summary

Summary

Steam crackers can process a wider range of feedstocks than their original design

Lighter feeds increase gross margin due to lower feed consumption and lower feed price

- Outweighs value of lost by-products
- Broadly true

Heavier feeds can increase gross margin due to higher by-product values

- Value of increased by-product production outweighs increased feed cost
- More sensitive to yields and to product pricing than lighter feeds

- Feed flexibility is the best way to take advantage of unpredictable market fluctuations

- Feed flexibility should be considered at every phase of a project
  - Cost and downtime of adding feed flexibility is minimized when done with an expansion or during a grassroots design

Questions & Answers

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