Overall Energy Conservation in both process unit and utility through HERO Service & Energy Saving Distillation Technology *SUPERHIDIC®*

Singapore Energy Efficiency Symposium for the Energy and Chemicals Industry

October 15th and 16th 2019

TOYO ENGINEERING CORPORATION

Target Customers

Those who are struggling to find further solution for energy-saving and reduction of GHGs emission.

e.g. Pinch technology has been already done...
Lots of process/plot constraints

What TOYO Offers in this presentation...

- Technology applied to distillation unit
- Methodology to bring you new idea

Energy Saving Distillation Technology

SUPERHIDIC®

October 2019

TOYO ENGINEERING CORPORATION

Summary

- Proven technology through commercial production plant operation
- Offering tremendous energy conservation and reduction of GHGs emission to conventional distillation by 40-75%!
- Reducing utility consumption at not only reboiler (steam, fuel gas, fuel oil) but also condenser (cooling water, electricity at AFC)
- Can be applied to both new plants and revamping/upgrading
- Attractive economics like IRR of 15-40% in suitable applications

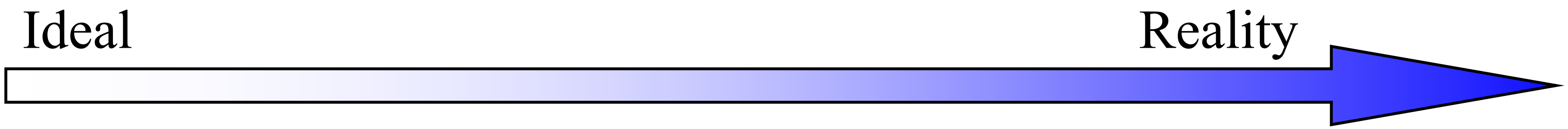
Summary

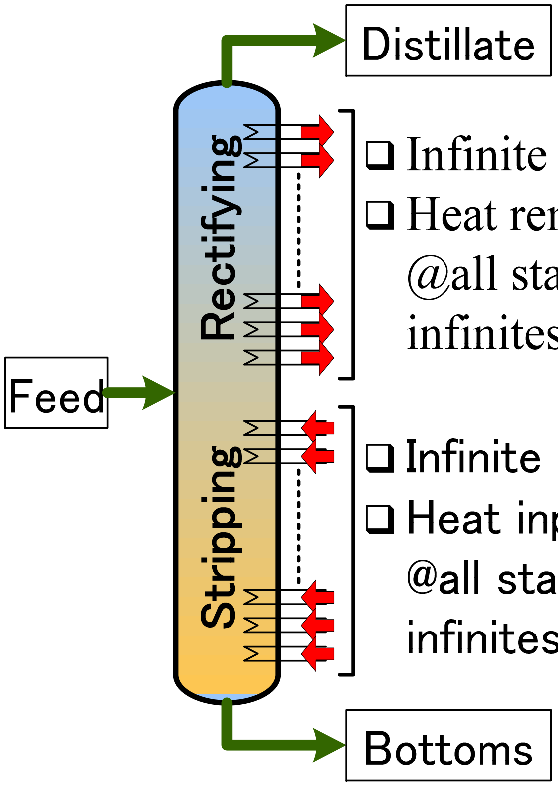
Process Unit	Service Name	Energy Saving	Example				
			Capacity	Conv. Dist.	*SUPERHIDIC®*	
				Reb Duty	Reb Duty	Comp Power
		[%]	[kMTA]	[MW]	[MW]	[MW]
p-Xylene	Tol. Column	68	1380 p-Xylene	238	0	27.5
p-Xylene	Finishing Col.	45		98.1	0	19.6
p-Xylene	Xy. Splitter	54		181	12.6	26.1
m-Xylene	m-Xylene Col.	50	23 t/h feed	4.3	0	0.78
o-Xylene	o-Xylene Col.	73	17.5 t/h feed	9.93	0	0.9
C4 Isom.	C4 Splitter	57	180 iC4	11.6	0	1.85
C5 Isom.	C5 Splitter	64	270 iC5	29.7	0	3.91
C6 Isom.	De-iC6	48	46 t/h feed	6.98	0	13.2
C4 Dehydro.	BD Prefrac.	75	71 t/h feed	32.4	0	2.95
FCC	FCC NP Splitter	52	280 t/h feed	23.7	0	4.03
FCC	Light Cracked NP	44	30.2 t/h feed	24.4	0	4.87

Summary

Process Unit	Service Name	Energy Saving	Example			
			Capacity	Conv. Dist.	*SUPERHIDIC®*	
				Reb Duty	Reb Duty	Comp Power
		[%]	[kMTA]	[MW]	[MW]	[MW]
VCM	Light End Col.	43	200	5.37	0.27	1.03
VCM	Heavy End Col.	51	654 EDC	11.63	0	2.07
IPA	Azeotropic Col.	41	163	19.8	0.99	4.0
2EH	C4 Alde. Splitter	52	240 NBAL	10.9	0	1.9
SM	EB/SM Splitter	41	240 SM	25.2	0	5.4
MEK	**MEK Fractionator**	**56**	**100 MEK**	**6.0**	**0**	**0.9**
1-Butene	1st Column	74	63 1-C4=	9.62	0	1.67
	2nd Column			8.11	0	
Iso-Butene	iC4= Fractionator	62	70 iC4=	22.8	0	3.15
Caprolactam	Cyclohexane Col.	50	11.5 Anon	13.5	1.05	2.07

Heat Integrated Distillation Column
- Fundamental -

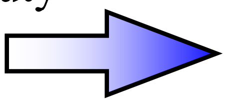


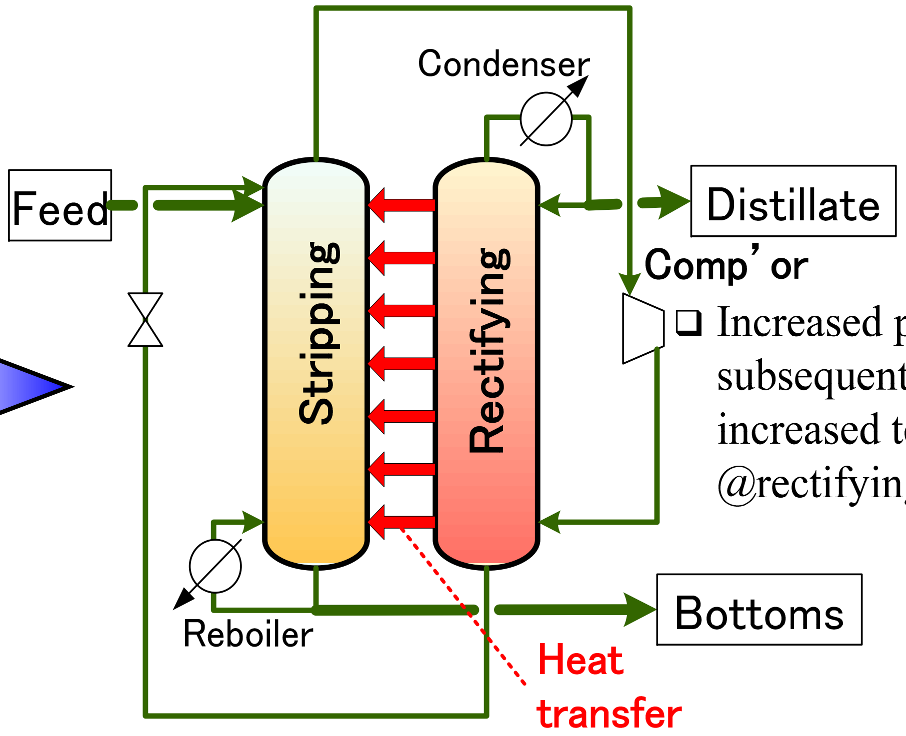


- Infinite stages
- Heat removal
  @all stages with
  infinitesimal duty

- Infinite stages
- Heat input
  @all stages with
  infinitesimal duty

Reversible Distillation





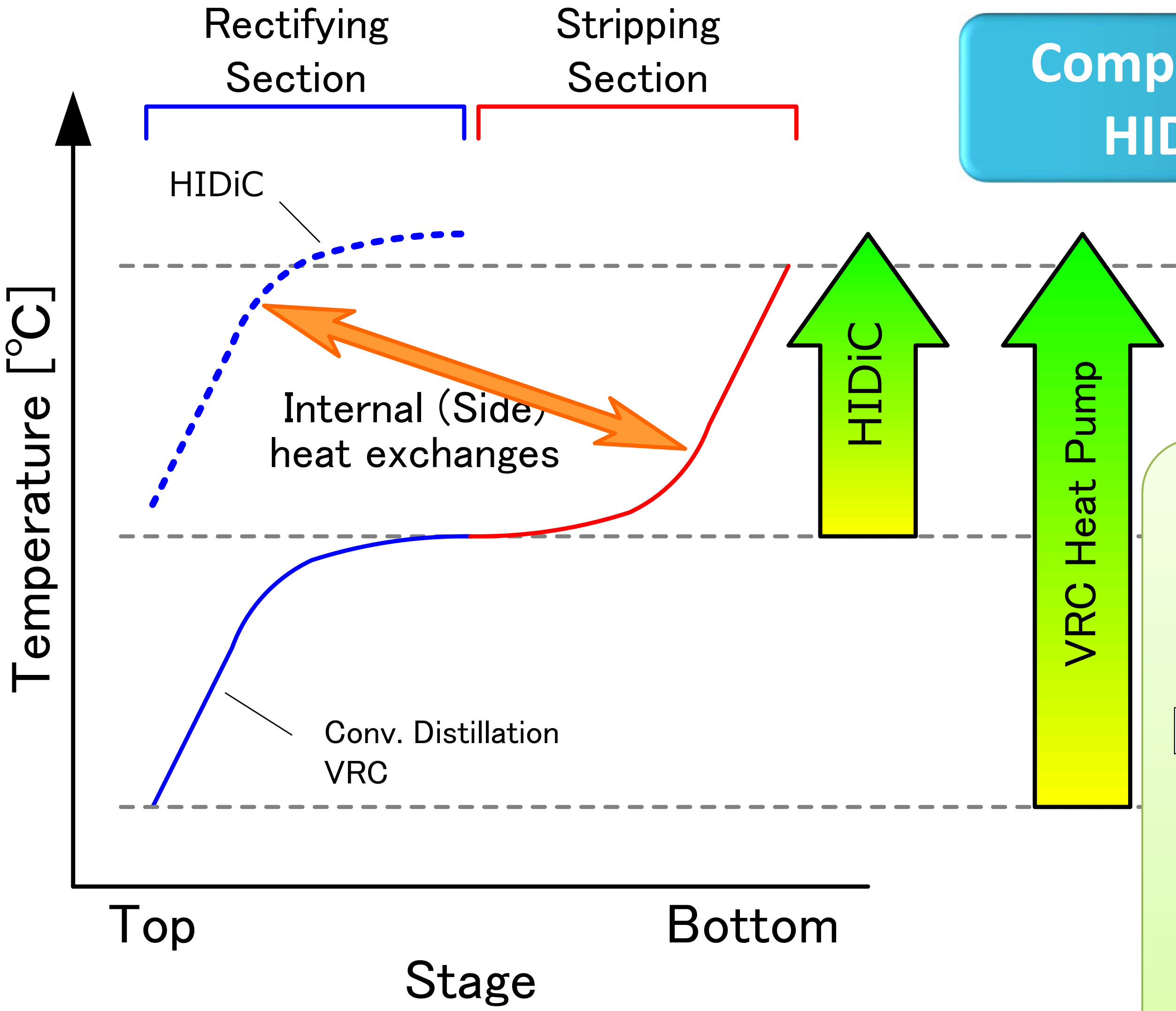
- Increased pressure, subsequent increased temp. @rectifying section

HIDiC

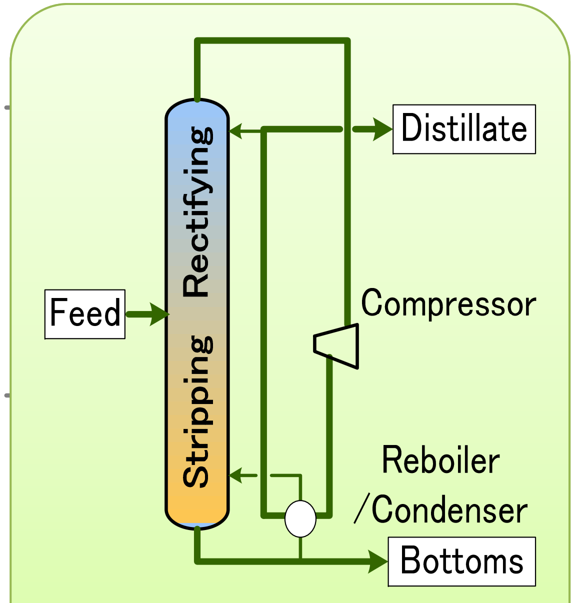
TOYO ENGINEERING CORPORATION ©2019

Fundamental
- Heat Integrated Distillation Column -

TOYO ENGINEERING



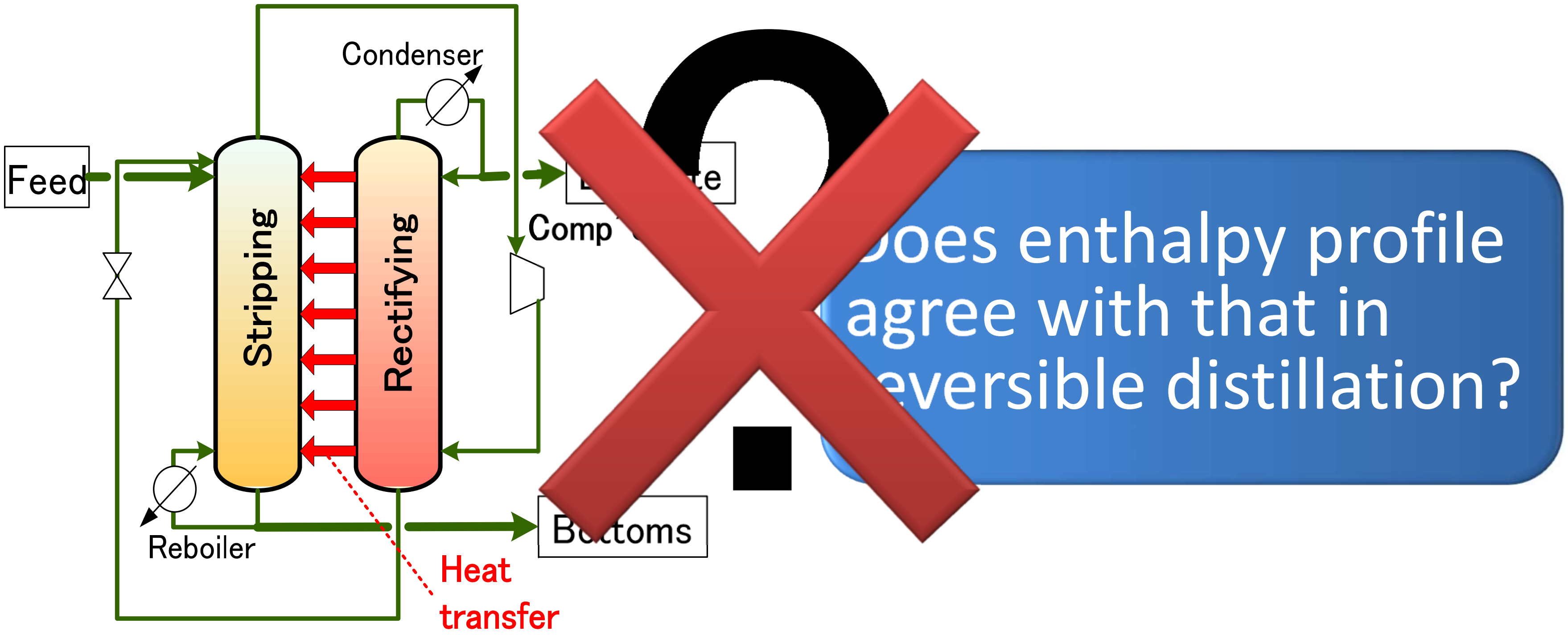
Compression Ratio
HIDiC < VRC



VRC Heat Pump

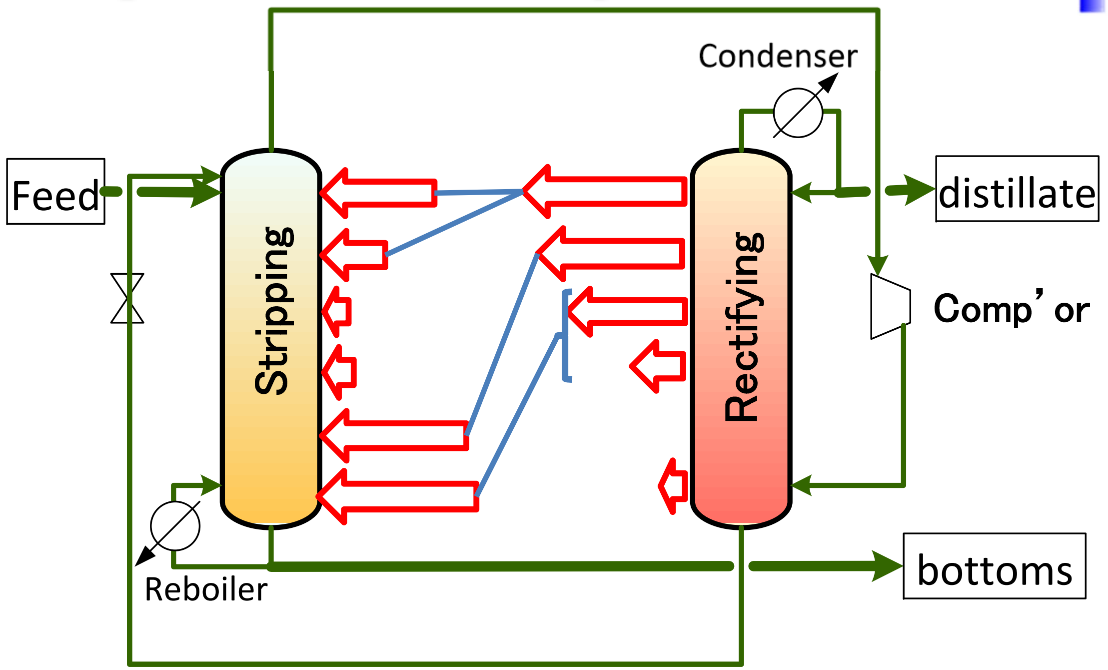
TOYO ENGINEERING CORPORATION ©2019

Conventional HIDiC



Evolved HIDiC - *SUPERHIDIC®* -

Example of Ideal Heat Duty Allocation



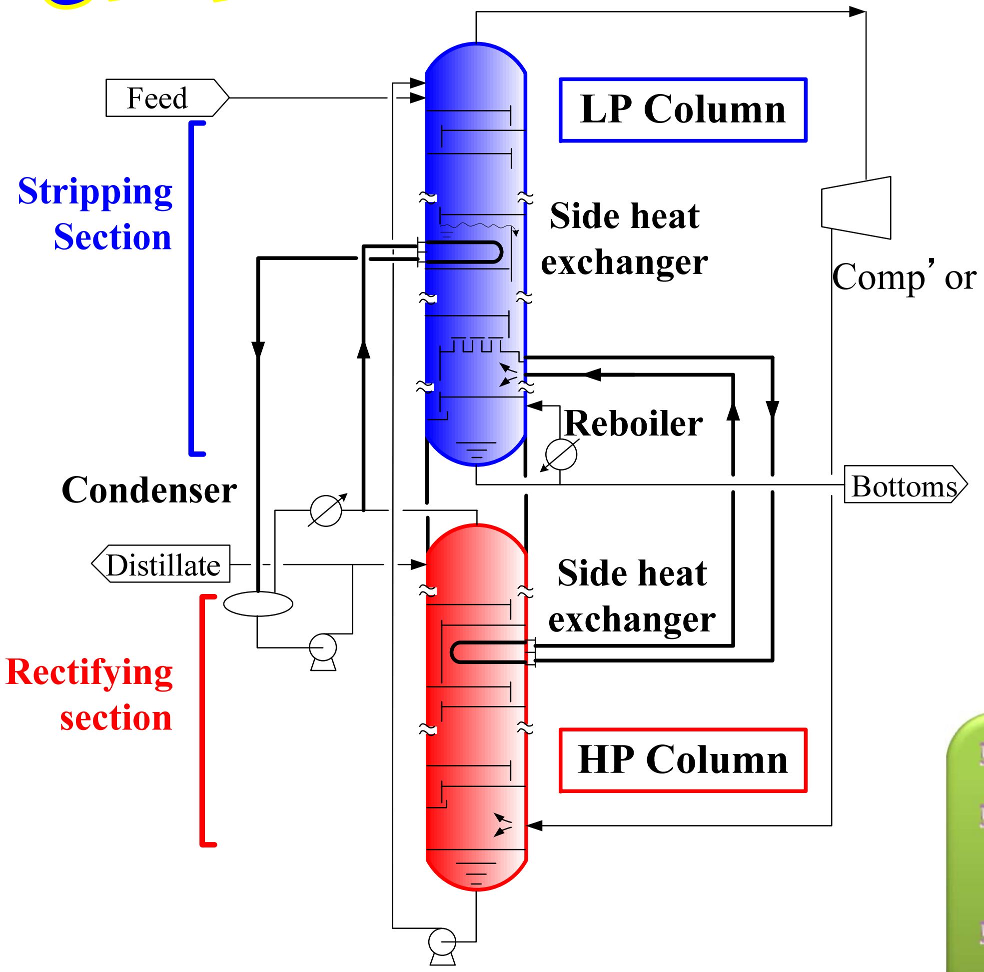
- Findings through intensive thermodynamics study
  - Ideal heat duty is dependent on the composition (stage).
  - Some composition may require heat while some others may not. Thus, discrete side H/Ex allocation.
  - Seldom to have ideal heat duties at the same elevation.
  - Stage having similar heat duty demand should be combined.

Inappropriate side H/Ex manner = Increase in column loading in vain
= Increase in compressor

Discrete & a few side H/Ex
Different heat duty at each side H/Ex
Appropriate stage to be exchanged not at same level

Evolved HIDiC - *SUPERHIDIC®* -

Simple but Better



Patent registered by Toyo/AIST

【 Features 】

- Side exchangers
  - Normal stabbed-in type H/Ex (Normal S/T H/Ex can be used)
  - Installed at the desired composition
  - Freedom in pairing of stages
  - Heat transfer area is variable
  - Limited number (around 4) only
- Column
  - Strip. sect. elevated above rect. sect.
    → No pump is required for circulation
  - Normal tray or packing

- Maintenance possible
- Applicable to any process scheme, *e.g.* side-cut product draw-off, multi-feed
- Optimal side heat duty allocation close to reversible distillation achievable

Actual Performance in Commercial Plant

TOYO ENGINEERING

- Awarded for world-1st HIDiC commercial application with *SUPERHIDIC*® in 2014 3Q
- Contract Summary
  - Client : Maruzen Petrochemical
  - Site: Chiba, Japan
  - Process Unit : MEK
  - Scope : License & EPC TKLS
  - S/U : FY 2016 Aug.
  - Replacement of conventional distillation column
- Results
  - Energy Conservation : 57 % reduction to conventional distillation
  - Stable Operation w/ 0 kW Reboiler Duty
  - More than 3 years commercial operation

TOYO ENGINEERING
Toyo Engineering Corporation
8-1, Akanehama 2-chome, Narashino-shi,
Chiba 275-0024, Japan
Tel: +81-47-454-1113 Fax: +81-47-454-1160

News Release

World's First Practical Use of Innovative Energy Saving Distillation System
- Approximately 50% energy savings compared to conventional systems -

November 7, 2014
Toyo Engineering Corporation

Toyo Engineering Corporation (TOYO, President and CEO Katsumoto Ishibashi) has been awarded a contract to commercialize an energy-saving distillation system, called *SUPERHIDIC*®, that was patented in 2011. The contract is for a distillation column in a methyl ethyl ketone (MEK) production plant to be constructed by Maruzen Petrochemical Co. Ltd. (Ichihara City, Chiba, Japan).

The distillation operation that is generally used in oil refineries and petrochemical plants is a thermal energy intensive process, where the bottom of distillation towers is heated using a reboiler and, at the same time, overhead gas is cooled using a condenser. To save energy in the distillation operation, a range of technologies has been proposed to date. Since the concept of Heat Integrated Distillation Column (HIDiC) was announced in the 1970s as a process promising ultimate energy-saving performance, HIDiC has been studied worldwide; however, practical application of the process has not yet taken place.

Advancing the concept of HIDiC and applying well proven distillation and heat-transfer technologies, TOYO has developed *SUPERHIDIC*®, a distillation system that produces high economic efficiency while retaining the maintainability of normal distillation columns. *SUPERHIDIC*® enables 40%-60% energy savings in many cases within the distillation process by providing optimal internal heat exchange.

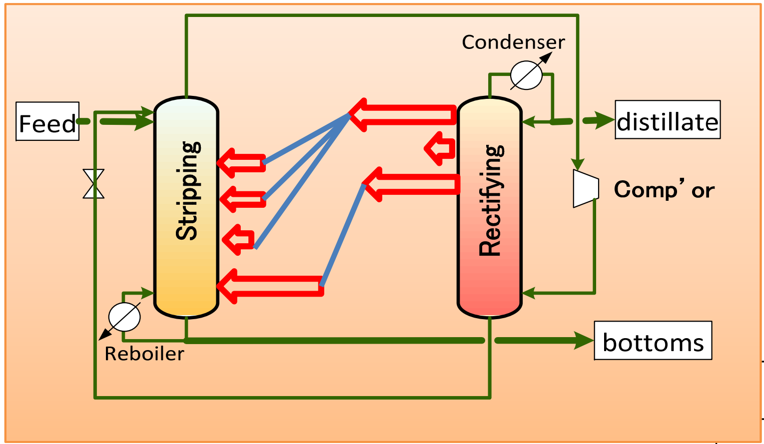
Taking this opportunity to carry out commercialization, TOYO will strive to expand the application of *SUPERHIDIC*® to various distillation columns, thus helping reduce energy usage in oil refineries and petrochemical plants.

Contract Summary

■Client:	Maruzen Petrochemical Co. Ltd.
■Contractor:	Toyo Engineering Corporation
■Site:	Ichihara City, Chiba, Japan
■Facilities:	Distillation column in methyl ethyl ketone (MEK) production plant
■Scope:	Provision of *SUPERHIDIC*® technology and basic engineering

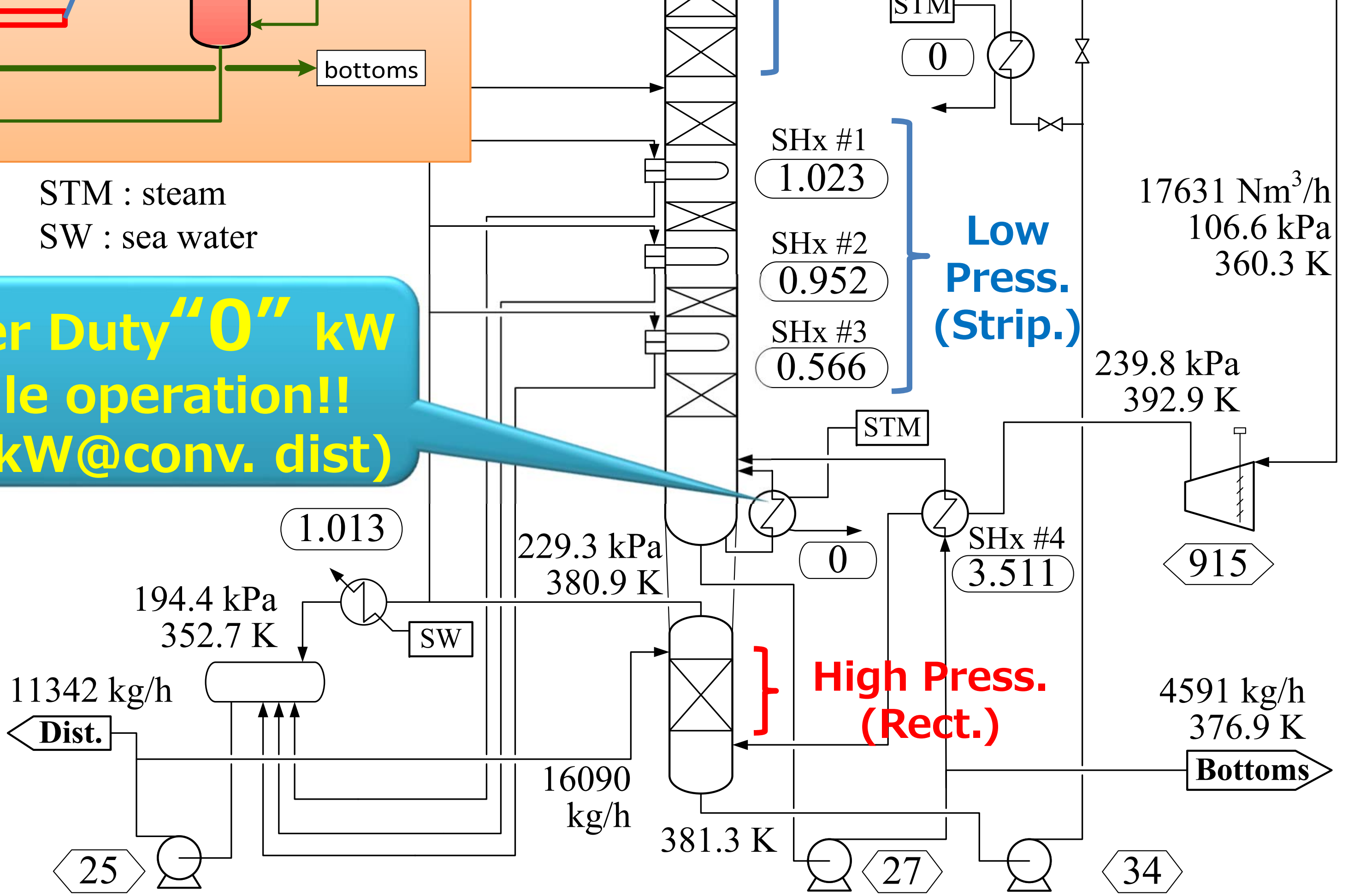
For inquiries, contact:
TOYO Engineering Corporation
Corporate Communications Division [SATOU Kenji, FUKASAWA Yuki]
Phone: +81-47-454-1113

Actual Performance in Commercial Plant



STM : steam
SW : sea water

Reboiler Duty "0" kW
in stale operation!!
(6135 kW@conv. dist)



Actual Performance in Commercial Plant

		SUPERHIDIC	Conv. Distillation
Feed rate	[S kL/h]	19.5	19.5
Operating pressure			
Low pressure column @OVHD	[kPa]	109	109
High pressure column @OVHD	[kPa]	229	-
Separation specifications			
MEK @distillate	[wt%]	99.94	99.94
MEK @bottoms	[wtppm]	200	200
Energy consumption			
Reboiler duty	[kW]	0	6135
Compressor power	[kW]	915	0
Reflux/dist. Pump	[kW]	25	55
Bottoms pump	[kW]	27	10
Recycle pump	[kW]	34	-

Energy Saving
56.7%
to Conv. Distillation

$$\text{Energy Saving [\%]} = 1 - \frac{Q_{r\text{-}SH} + W_{SH}/0.366}{Q_{r\text{-}conv} + W_{conv}/0.366} \times 100$$

$Q_{r\text{-SH}}$: Reboiler duty in SUPERHIDIC [MW]
$Q_{r\text{-conv}}$: Reboiler duty in conv. Distillation [MW]
W_{SH} : Compressor & pumps power in SUPERHIDIC [MW]
W_{conv} : Compressor & pumps power in conv. distillation [MW]

Actual Performance in Commercial Plant

TOYO ENGINEERING

GHGs Emission

[Conventional Distillation]

✓ Reboiler : 6,135 kWh/h

× 8,000 h/y × 3.6/1,000 GJ/kW × 0.0477 tCO2/GJ = 8,428 ton-CO_2/yr

✓ Pump : (55+10) kWh/h

× 8,000 h/y × 0.00050 tCO2/kWh = 260 ton-CO_2/yr

Total CO_2 emission : **8,688** ton-CO_2/yr

[*SUPERHIDIC*®]

✓ Reboiler : 0 kWh/h

× 8,000 h/y × 3.6/1,000 GJ/kW × 0.0477 tCO_2/GJ = 0 ton-CO_2/yr

✓ Pump + Compressor :(25+27+34+915) kWh/h

× 8,000 h/y × 0.00050 tCO_2/kWh = 4,004 ton-CO_2/yr

Total CO_2 emission: **4,004** ton-CO_2/yr

Reduction of CO_2 emission : 8,688 – 4,004 = 4,684 ton-CO_2/yr

→ 54% reduction

TOYO ENGINEERING CORPORATION ©2019

Recommendable Service for *SUPERHIDIC®*

- Service where *SUPERHIDIC®* offers attractive energy saving and economics
  - Temp. difference btw OVHD and bottoms even up to 80 deg C
    - Much larger difference compared to vapor re-compression heat pump system
  - Large scale reboiler and/or condenser duty
  - Expensive utilities
  - Less fouling

Awards

- 2014 Nikkei Green Innovation Prize
- 2017 ENAA Engineering Excellence Award
- 2018 Energy Conservation Grand Award (METI Prize)
- 2018 SCEJ Award for Outstanding Technical Development
- 2018 JPI Award for Technological Progress
- 2019 SSEJ Award for Outstanding Technical Development

Next

- How to apply such nice technology to your plant

- How to achieve energy-saving and reduction of GHGs emission even without such super-technology

Confidential

TOYO ENGINEERING

Energy Conservation & Reduction of GHGs Emission for Overall Process/Utility Plant by Mathematical Optimization

— Hybrid Energy system Re-Optimization —

2019

TOYO ENGINEERING CORPORATION

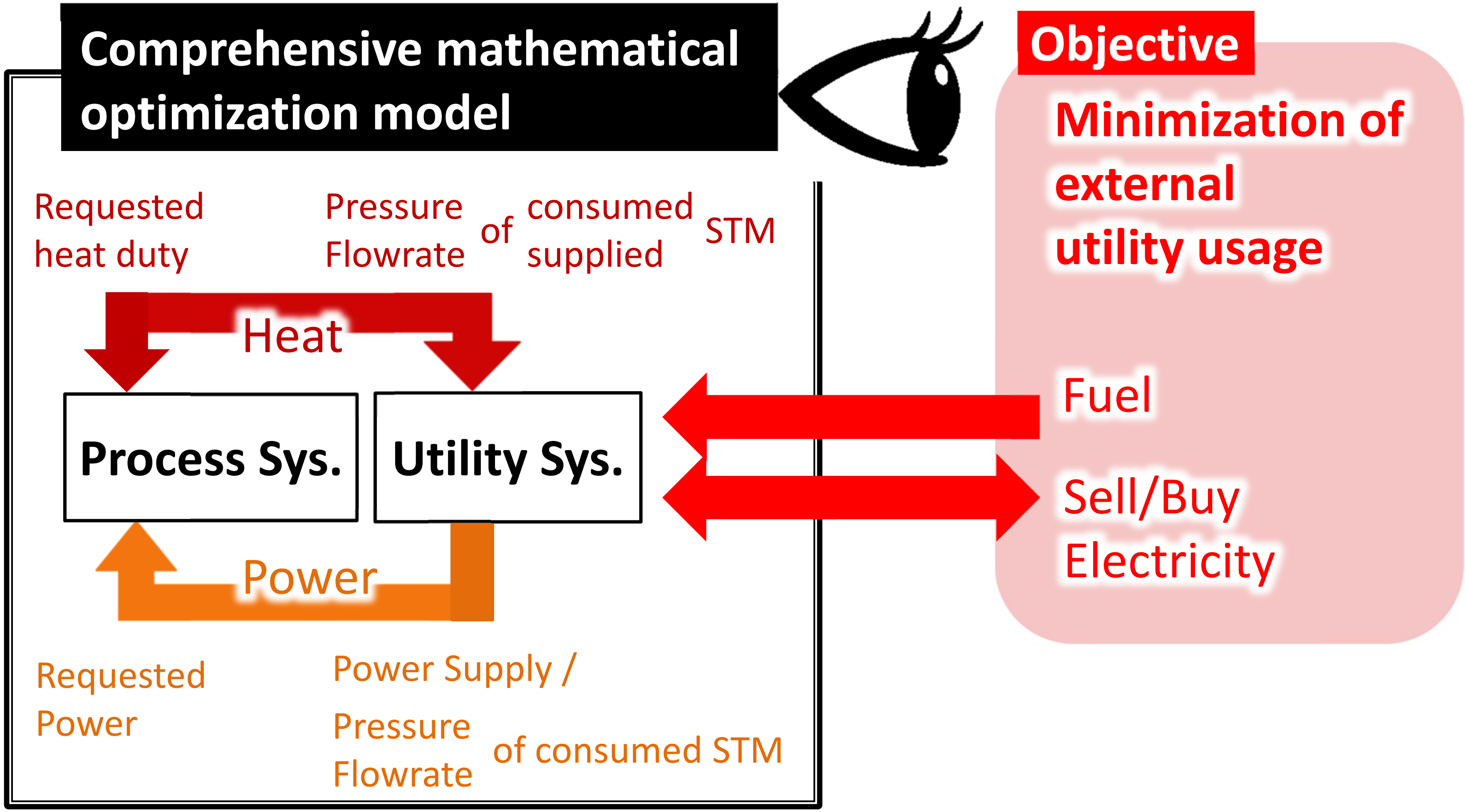
Agenda

- Overview
- Illustrative example (on the presentation only)
- Features of optimization model
- Achievements in a national project
- Business scheme

TOYO ENGINEERING CORPORATION ©2019

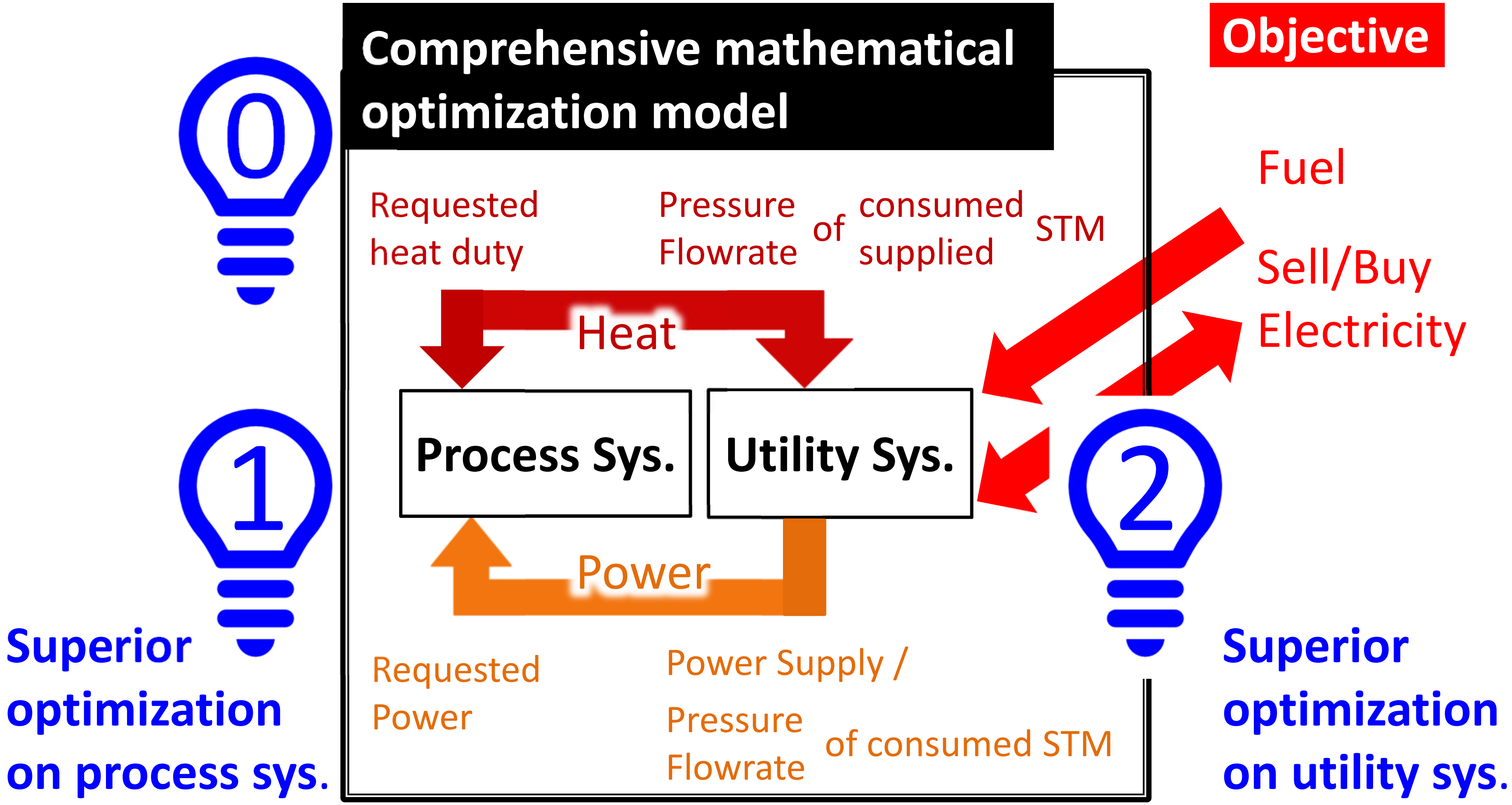
Simultaneous Optimization on both Process and Utility Systems

Comprehensive model optimizes both systems simultaneously for direct minimization of external utility resource usage.



What makes such big difference?

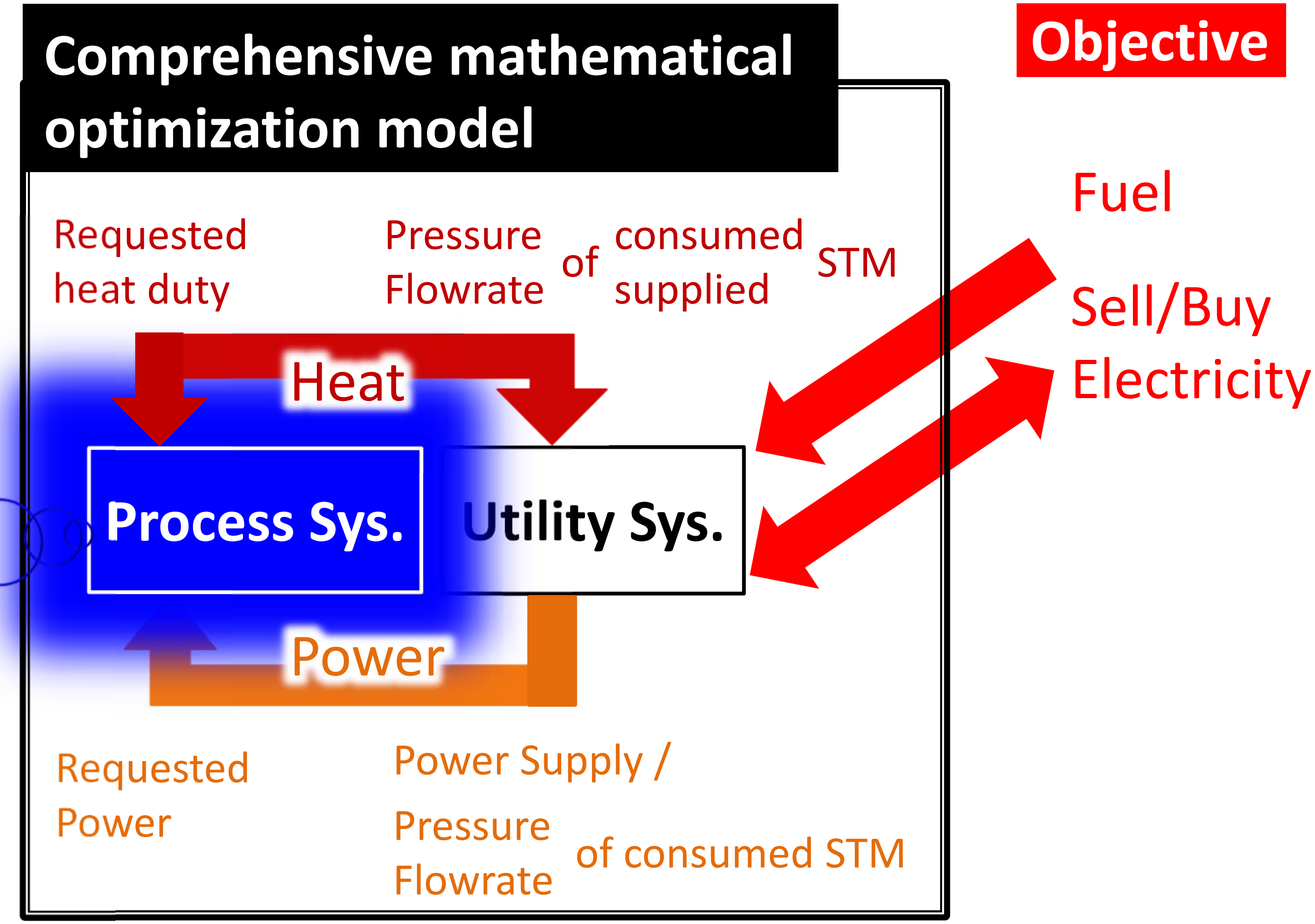
Primal *three* features for breaking the limit of conventional approaches, such as pinch analysis



Superior Process System Optimization

- ✓ Implementation of new HEXs
- ✓ Multi-effect dist. intensification
- ✓ Implementation of heat-pump distillation

etc…

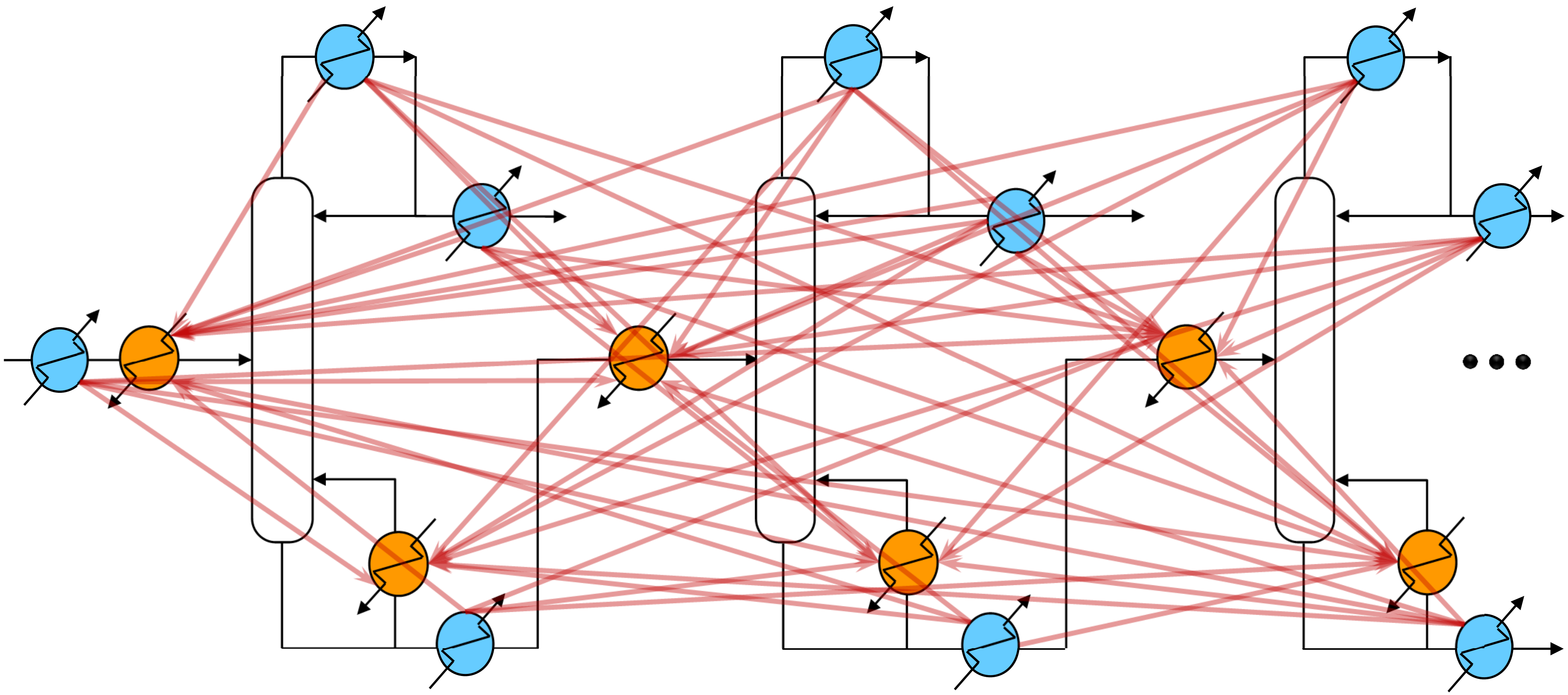


Optimization on Heat Exchanges

<u>All options</u> which might be effective are covered.

- ✓ Cooling: Condenser, heat recoveries at outlets
- ✓ Heating：Reboiler, feed preheaters

<u>From the all combinations, effective configuration is selected.</u>

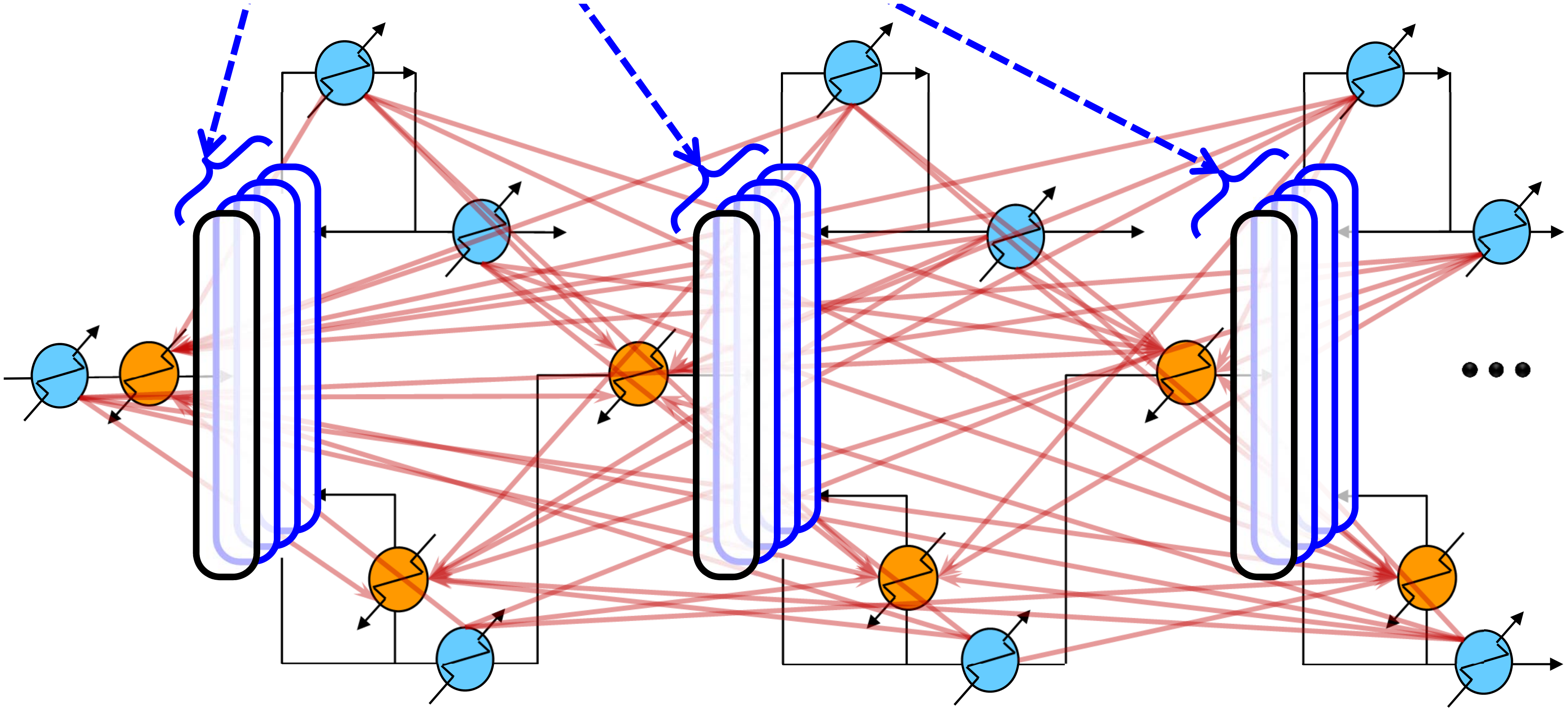


TOYO ENGINEERING CORPORATION ©2019

Optimization on Operating Pressure

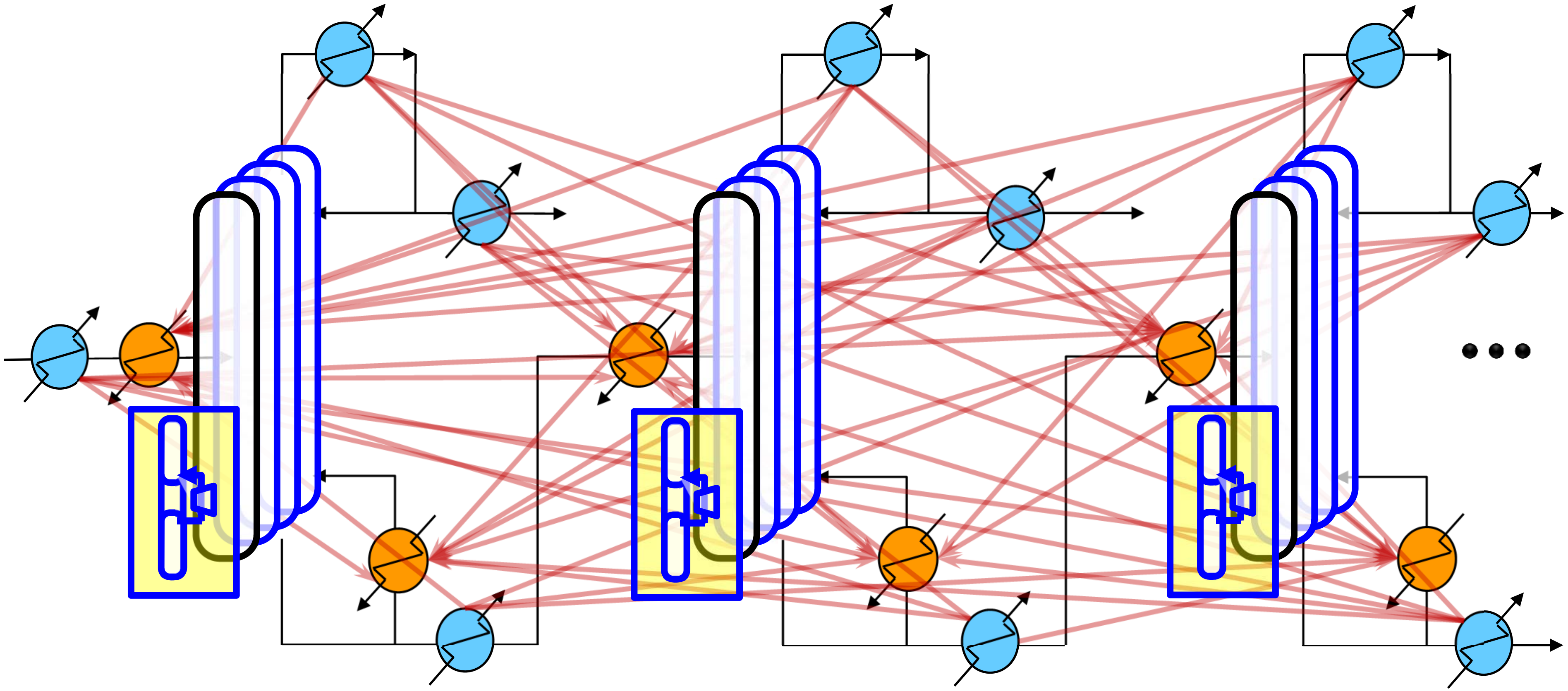
Operating pressures of distillation columns are also optimized

Linearized models for
several ranges of operation pressure are embedded.



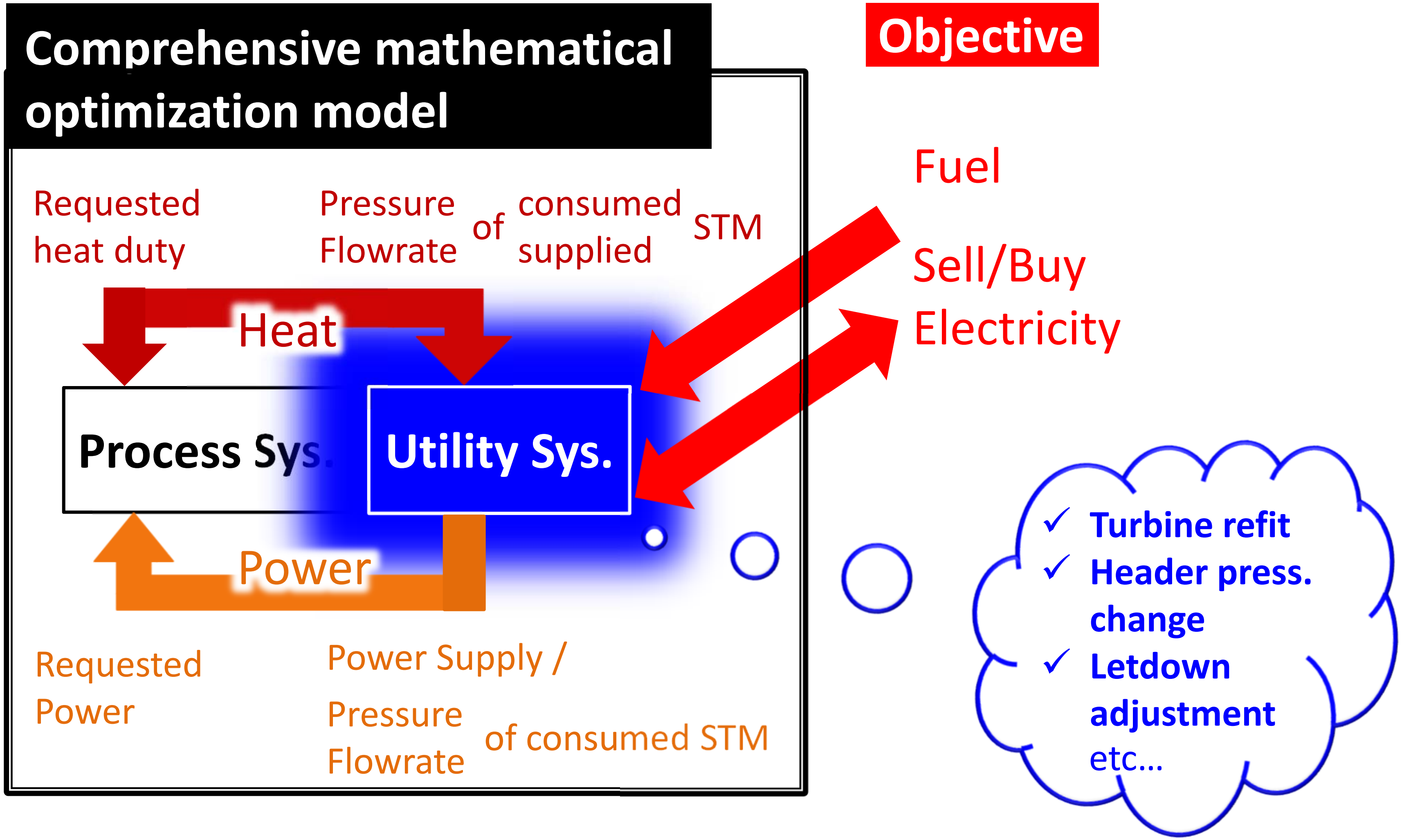
Examination of Heat-Pump Distillation

As for each distillation column,
Implementation of heat-pump distillation — especially SUPERHIDIC®, is also examined.

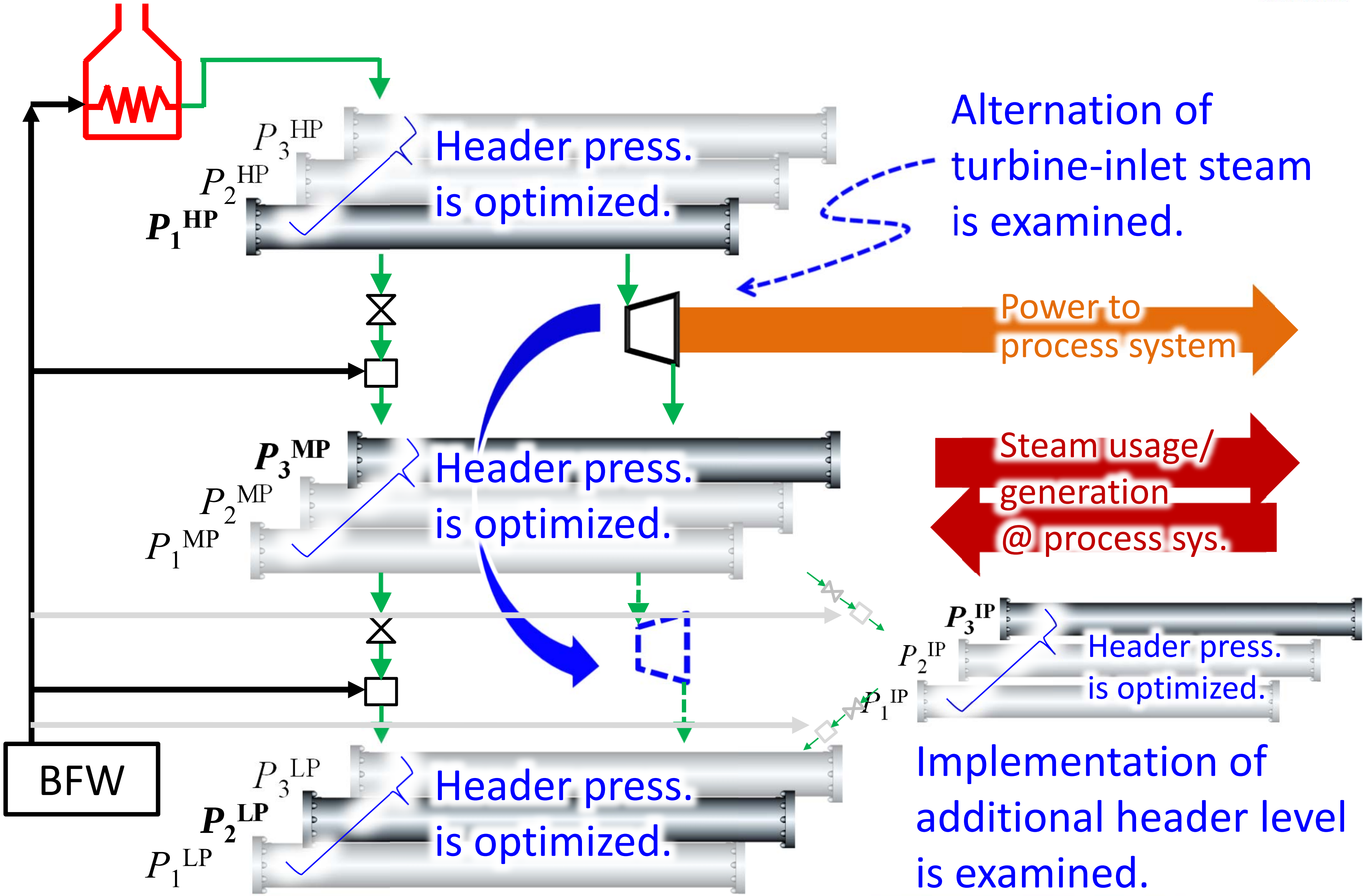


TOYO ENGINEERING CORPORATION ©2019

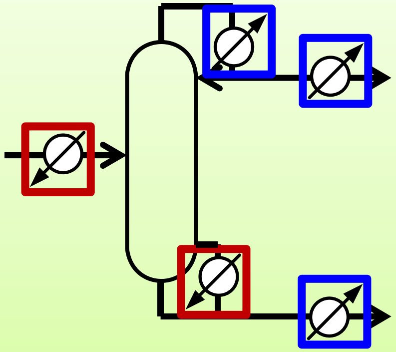
Superior Utility System Optimization



Optimization on Steam System



Scale of Optimization



In the case of
x 6 columns & 4 levels of STM headers

- ✓ # of ope. press. ranges: 4
- ✓ # of feed state ranges: 4
- ✓ SUPERHIDIC® option: included
- ✓ # of candidate press. of each STM header: 3

Heat-exchange comb.		Dist. col. ope. range		STM header ope press.	
$2^{(2\text{x}6)\text{x}(3\text{x}6)}$	x	$(4^2 \text{ x } 2)^6$	x	3^4	$\cong$ **10^{75} conditions**

Corresponds to: $2^{(\text{\# of possible comb.})}$

Even this alone results in **10^{63} conditions**

Solve 1 case w/ 1 sec ⇒ 10^{57} years

HERO's efficient search using Mixed Integer Linear Prog. can find out the solution within moderate calc. time.

TOYO ENGINEERING CORPORATION ©2019

Customization for “Best” Modification

- **Precise performance diagnosis of existing equipments**
  - Design press. & temp.
  - Column hydraulics
- **Limitation on equipment modification**
  (Indirect consideration of CAPEX for the modification)
  - Column replace (entire replace/internal replace)
  - Heat exchanger replace
  - Piping installation for new heat exchanges
- **Condition of external utilities**
  - Available utility list (fuel, steam, electricity, etc)
  - Exportable utility list
  - Prices of the available/exportable utilities

TOYO ENGINEERING CORPORATION ©2019

Agenda

- Overview
- Illustrative example (on the presentation only)
- Feature of optimization model
- Achievements in a national project
- Business scheme

TOYO ENGINEERING CORPORATION ©2019

Achievements (through a National Project)

Case 1

		Current	Proposal	Energy Saving
HP Steam	[MW]	31.3	18.9	12.4 (39.7% Saving)

Case 2

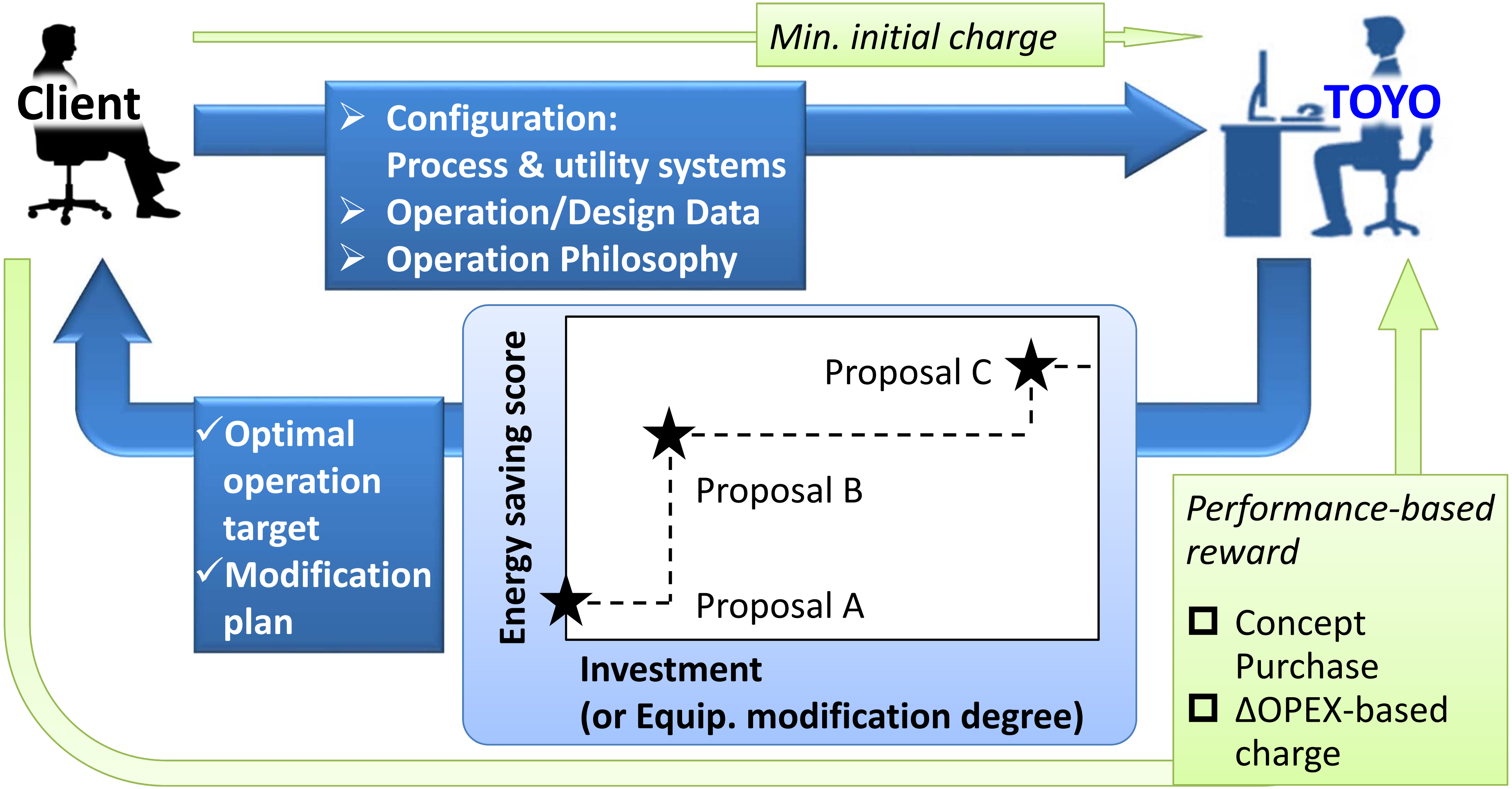
		Current	Proposal	Energy Saving
HP Steam	[MW]	9.24	9.24	0
MP Steam	[MW]	-2.7	-15.48	12.78 (473% for Sell)

Case 3

		Current	Prop. 1 Prop. 2	Energy Saving
Hot Oil	[MW]	12.32	9.85 MW 9.51 MW	Prop. 1: 2.47 (20% Saving) Prop. 2: 2.81 (23% Saving)

Business Scheme

Development of tailor-made model for specific process & utility configuration → **Proposal of "Overall" Optimum**



Information to be provided

Followings are to be provided at the beginning of the projects

- **Technical information regarding operation and design:**
  - PFD/UFD/MB・HB
  - Design pressure & temperature（MSD or writing down on PFD/UFD）
  - Plot plan
  - （Vapor-liquid equilibrium data, in some cases）

- **Constraints on modification:**
  - Possibility for replace/retrofit of each existing equipment
  - Possibility for installing new piping on pipe rack (room in rack)
  - Constraints on new heat exchanges (plot & process point of view)

- **Unit price of utilities:**
  Significant gap between actual and applied values severely misdirects the optimization.

- **Investment requirement:** Upper bound of investment & requested economics

TOYO ENGINEERING CORPORATION ©2019

Schematic Plan of Project Execution

Interview of prerequisite
- ☐ Contents mentioned in previous slide

Initial fee

Step 1: Development of modification plan regarding operation & equipment

TOYO's work：
- ✓ Establishment of trace model
- ✓ Mathematical optimization
- ✓ Summarizing equip. modification

Req. duration: 6 months

Rough evaluation of economics by client

Reward for basic concept

Req. duration: 1 months

Step 2: Support for precise estimation of CAPEX

TOYO's work:
- ✓ Clarifying modification plan on P&ID basis

- Final evaluation of economics
- FID

by client

Req. duration: 1 months

Step 3: Document finalization

TOYO's work:
- ✓ Finalizing the docs. for starting EPC

EPC Execution
(The contractor(s) can be others than TOYO.)

Start of operation

Performance -based reward

For a few years after 1st year operation

Output

- **Step 1: Information for rough estimation of modification costs**
  - ✓ PFD & UFD (with piping size of main process lines, without process control)
  - ✓ Major utility consumption summery (preliminary)
  - ✓ Equipment list with brief information
    (Process sketch with description of modification for reused equips.)
  - ✓ Brief plot plan
- **Step 2: Information for precise estimation of modification cost**
  - ✓ P&ID with markup of modified parts
- **Step 3: Finalized ver. of necessary documents for starting EPC**
  - ✓ PFD, UFD, MB･HB, Utility summary, P&ID
  - ✓ Equipment summary, Equipment datasheet
  - ✓ Brief plot plan

Thank you for your kind attention!

For more details…

TOYO Engineering Corporation

Business Development Division

Environment and Energy Management Development Department

Toshihiro WAKABAYASHI

Tel: 047 454 1571 / 090 6724 1074

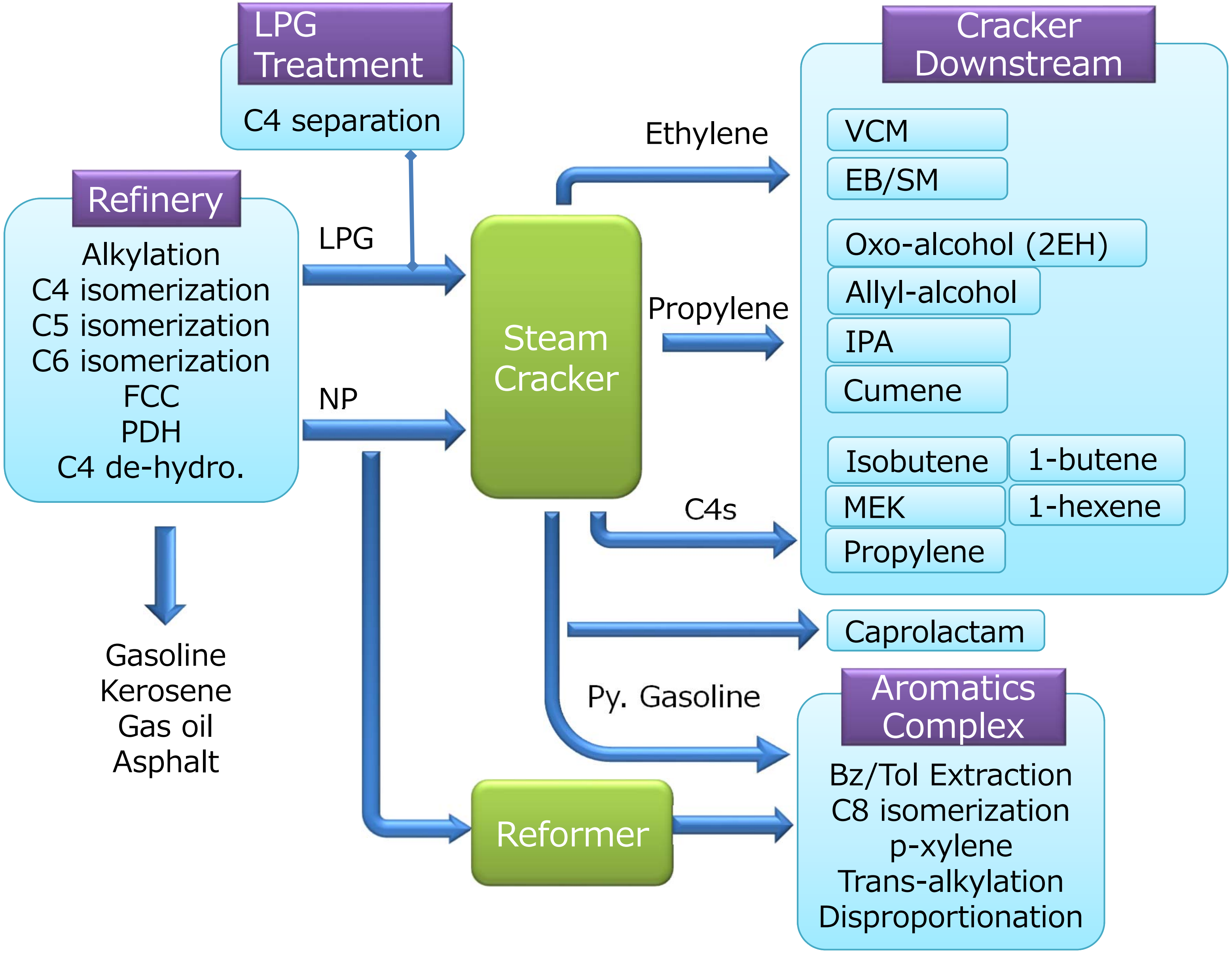
E-mail: toshihiro.wakabayashi@toyo-eng.com

TOYO ENGINEERING CORPORATION ©2019

TOYO ENGINEERING CORPORATION ©2019

Recommendable Service for *SUPERHIDIC*®

【 Process units that have been confirmed as suitable for SUPERHIDIC so far 】

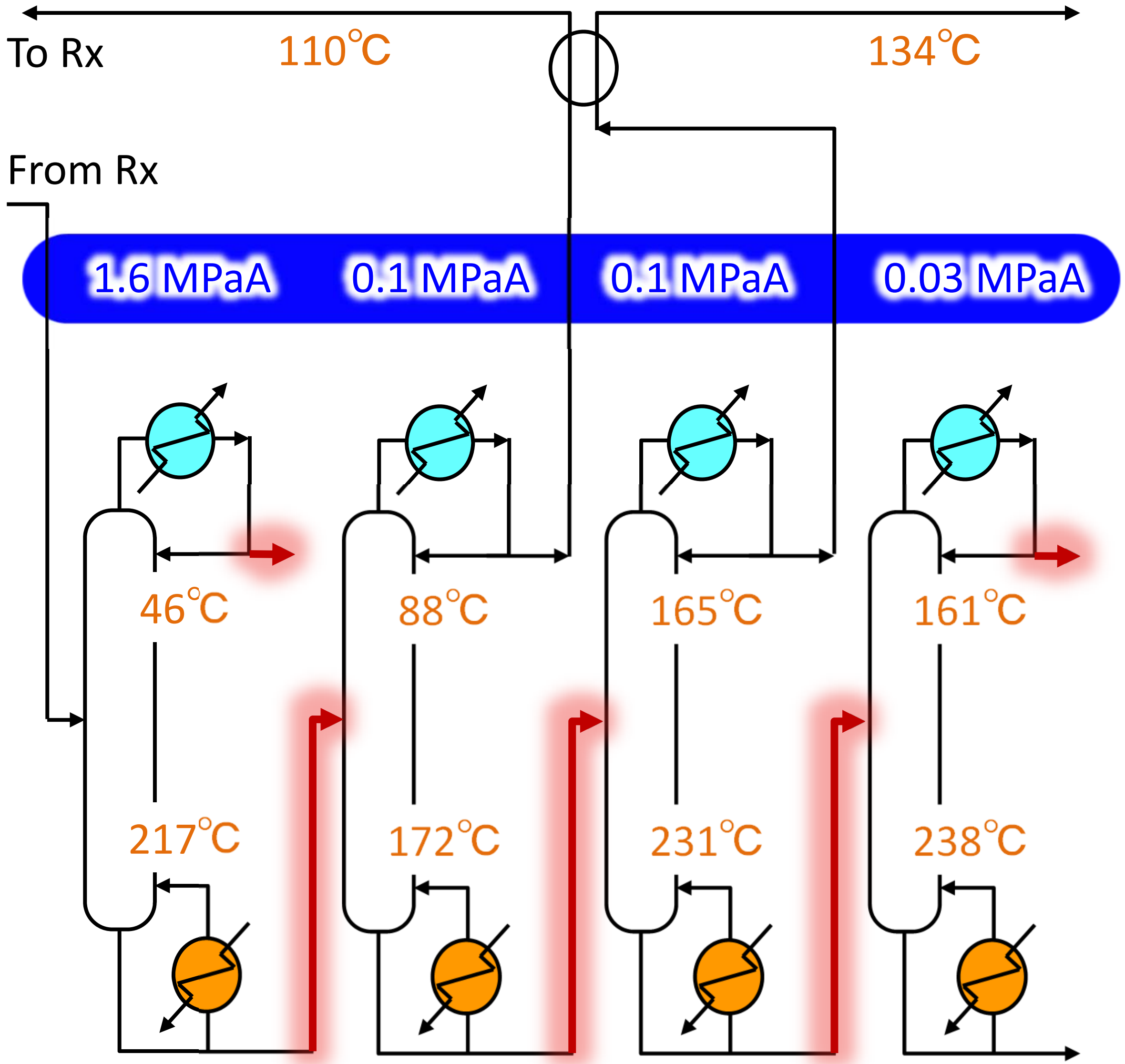


Conclusion

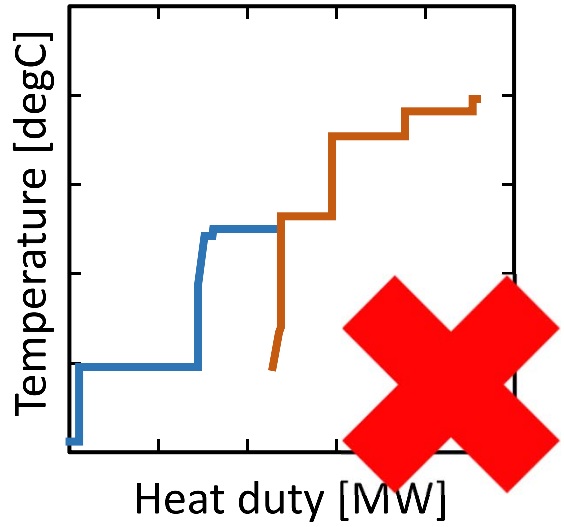
- HIDiC has been evolved to *SUPERHIDIC®*, which has been finally commercialized and becomes proven technology

- *SUPERHIDIC®* has achieved an energy saving of over 55% compared with conventional distillation
- The start-up operation has been carried out successfully as expected

Limitation of Pinch Analysis



Pinch analysis ?

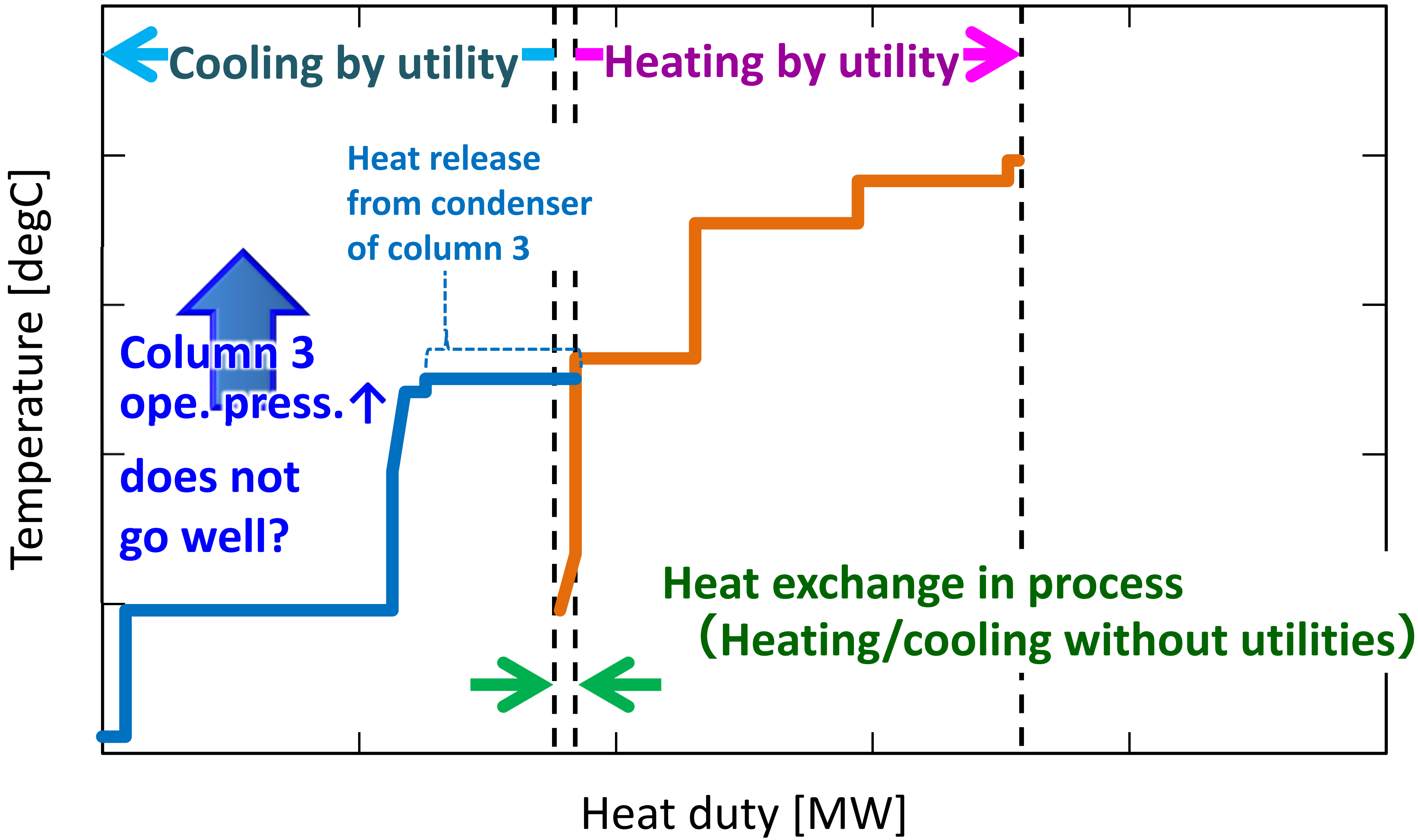


Additional Heat Exchange
at inlet/outlet flows?
Alternation of operation pressur

⇒Numerous candidates

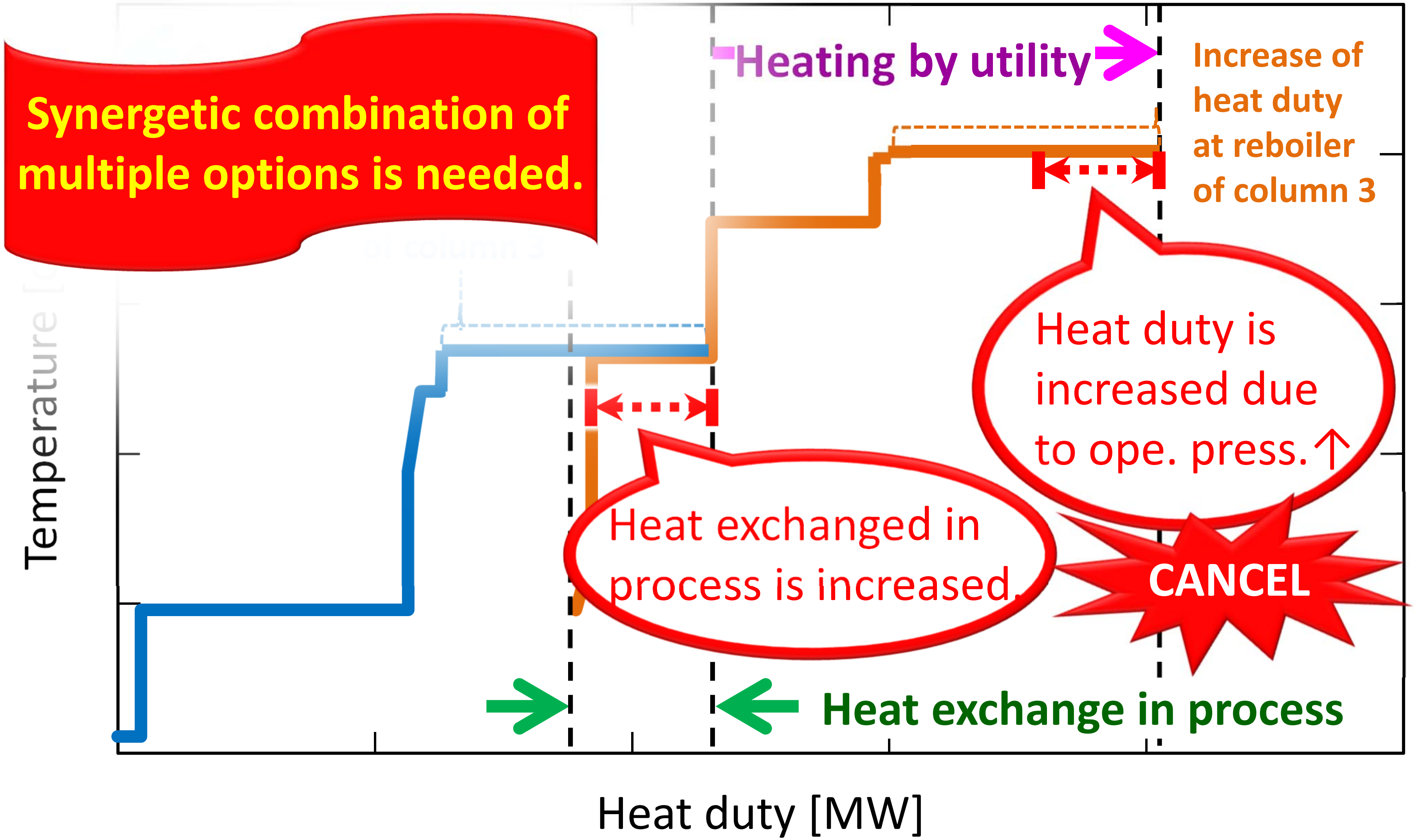
**Conv. methodology
+ trial & err
can hardly find
the global optimum**

Does Pinch Analysis + Trial & Err works?



NO! it does not in many cases

Trial & err often results in that unexpected demerit cancels the merit.



HERO's Result

29.8% (9.2 MW) Energy saving