CII Research Team 373

Reinventing Project Delivery Through Modular Chemical Process Intensification

James O'Connor, The University of Texas at Austin

Olivier J. LeNormand, The Dow Chemical Company

CII

2021 ECC Perspectives Conference

A fraction of the plant volume!

14% less OPEX!

1/5th the payback period!

Nearly twice the NPV !

HOW? MCPI

What is MCPI?

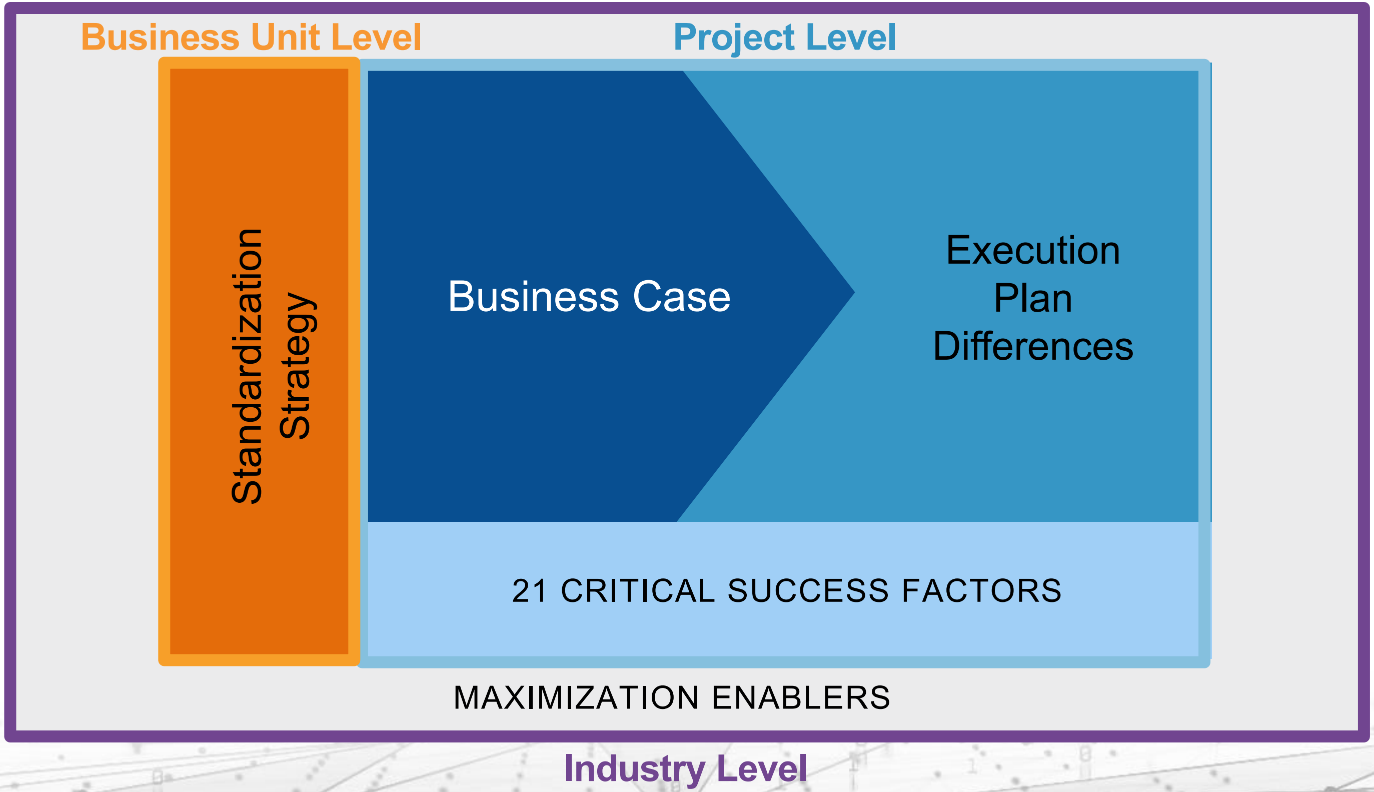
Modular Chemical Processing Intensification (MCPI) makes use of new technology that's smaller, safer, and more energy-efficient, and/or combining multiple operations into fewer ones

– Argonne National Laboratory

Modularization:

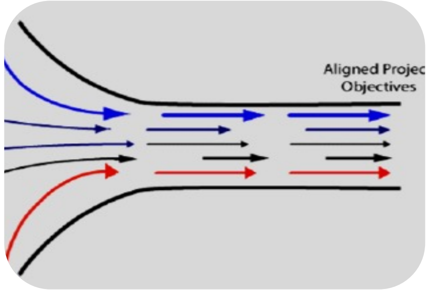
Moving work-hours to a beneficial fabrication site

Prior Modularization Research: Five Solution Elements (RT-283)



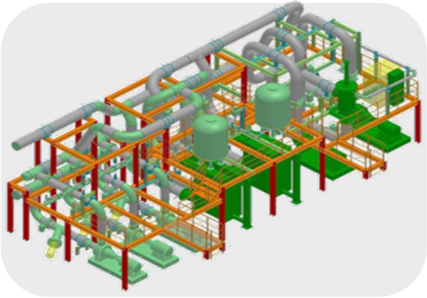
Top 4 (of 21) Modularization *Critical Success Factors*

Preliminary Transportation Evaluation



Alignment on Drivers

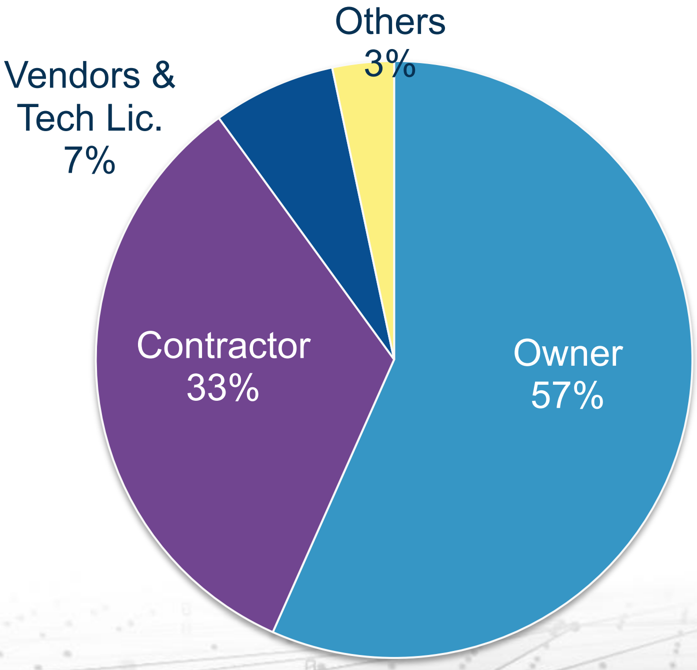
Owner's Planning Resources and Processes



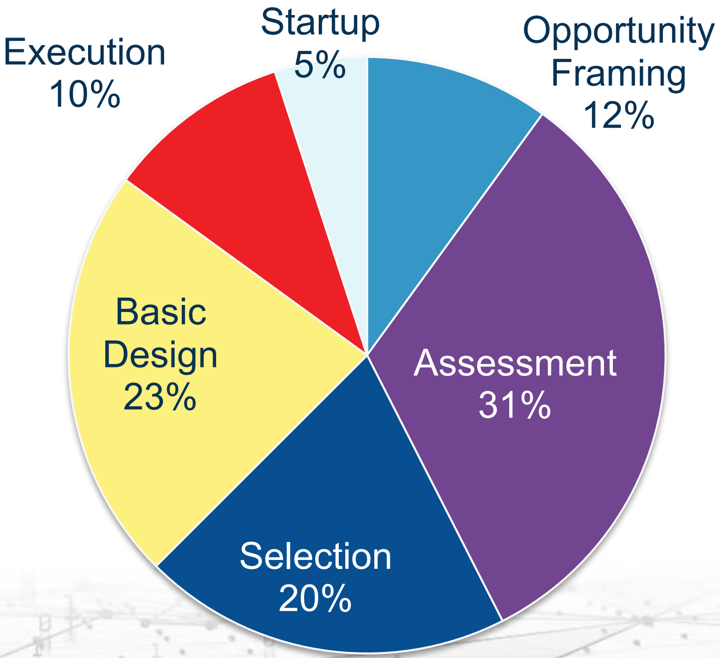
Timely Design Freeze

21 Critical Success Factors by Implementation Responsibility and Timing

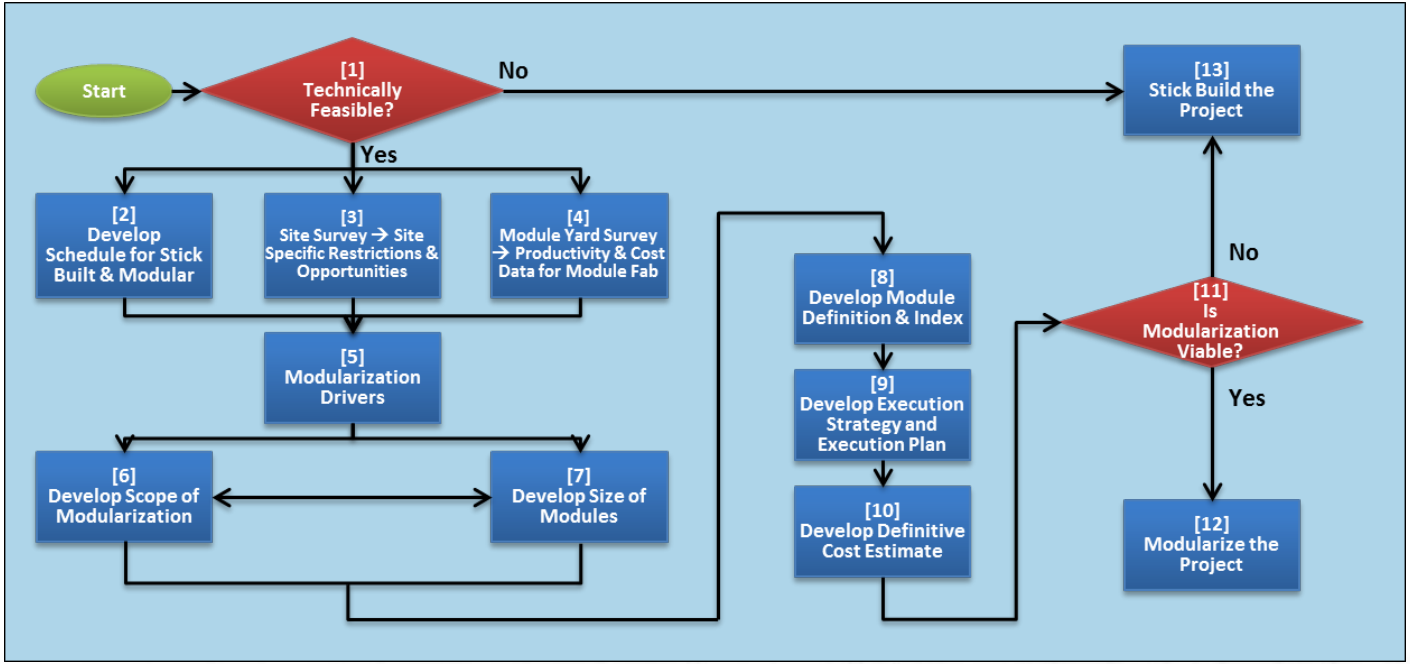
RESPONSIBLE LEAD



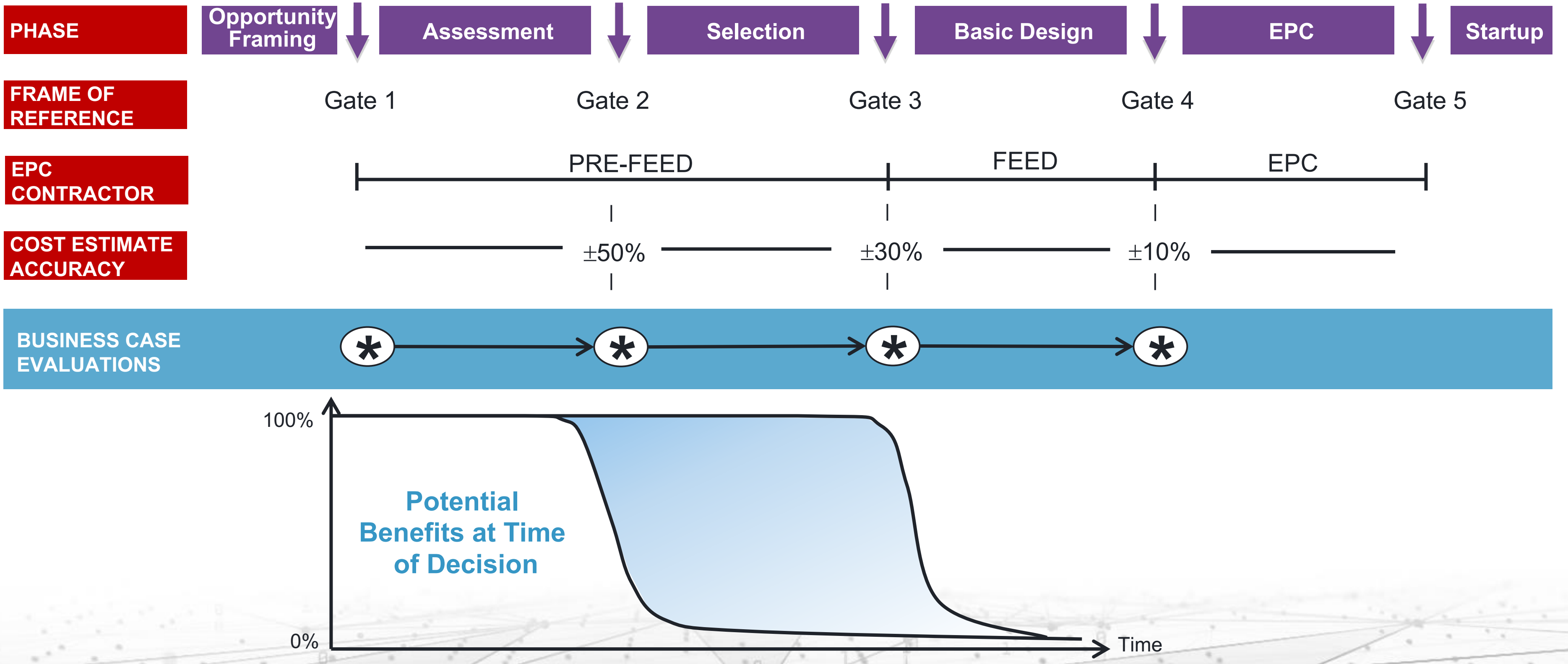
PROJECT PHASE



Business Case Analysis Model



Timing of Modularization Commitment



Execution Planning *Differences*

Ways of doing business can be ***very different*** with Modularization

107

items pertaining to 21 topics

Process Intensification

Benefits of Process Intensification

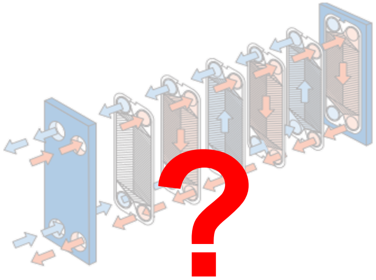
Process intensification is just innovation at the chemical process level

- Reduced capital investment
- Improved process safety
- Reduced energy use
- Lowered materials costs
- Increased process flexibility and inventory reduction
- Increased attention to quality
- Better environmental performance

Keller, G.E., and Bryan, P.F. (2000). “Process engineering: moving in new directions.” *Chemical Engineering Progress*, January, pp. 41-50.

Modular Chemical Process Intensification
Solar Thermochemical Processing

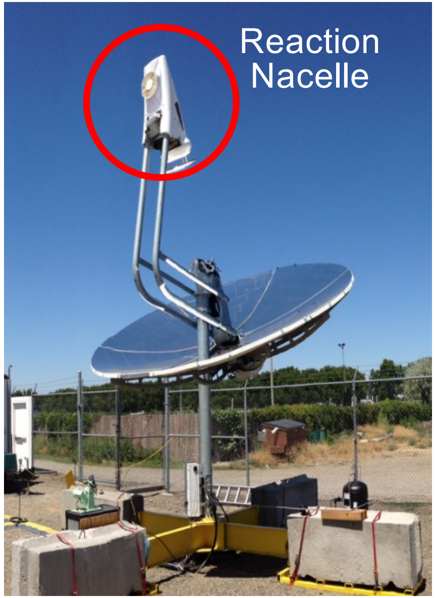
Plant construction is changing from conventional stick-built to the centralized manufacturing, transport, and delivery of manifold modules.



Chemical Process Intensification

Conventional Heat Exchanger

Parameter	Units	µchannel HX	Commercial HX
HX mass	Kg	5	70
HX volume	L	1.25	35
Duty	Watts	3500	3500
Effectiveness	%	87	<80
Side 1, Air dP	in H2O	4.3	4.3
Side 2, Air dP	in H2O	3.1	3.1



PNNL Heat Exchanger

Pacific Northwest NATIONAL LABORATORY

14X reduction in mass

28X reduction in volume

Higher effectiveness

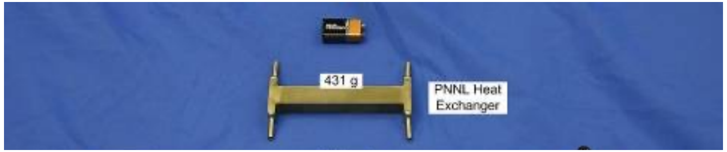
Chemical Process Intensification

Conventional Heat Exchanger

Parameter	Units	PNNL HX	Commercial HX
HX mass [1]	g	432	2285
HX volume [2]	cm^3	134	~1278
Duty	W	155	136
Effectiveness	%	92.2	80.0
Side 1, Air dP	psi	0.3	<1 psi
Side 2, Air dP	psi	0.9	< 1 psi

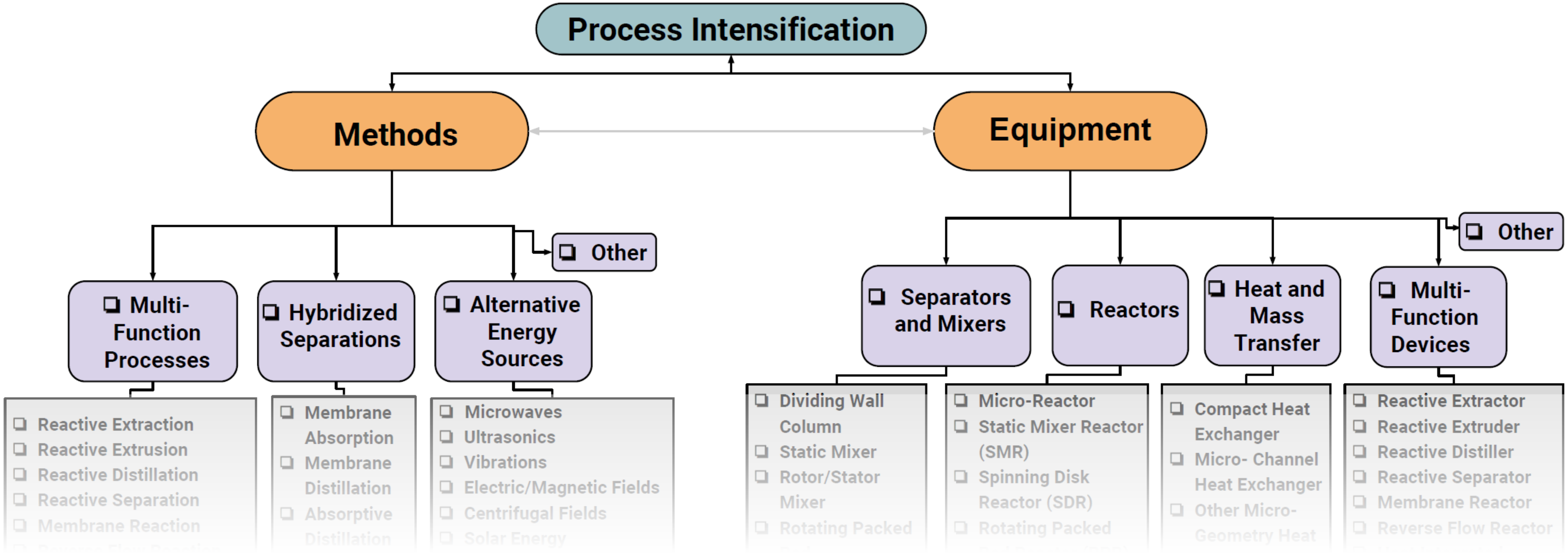
[1] Mass does not include tubing connections.
[2] Approximate volume occupied by heat exchanger.

PNNL Heat Exchanger



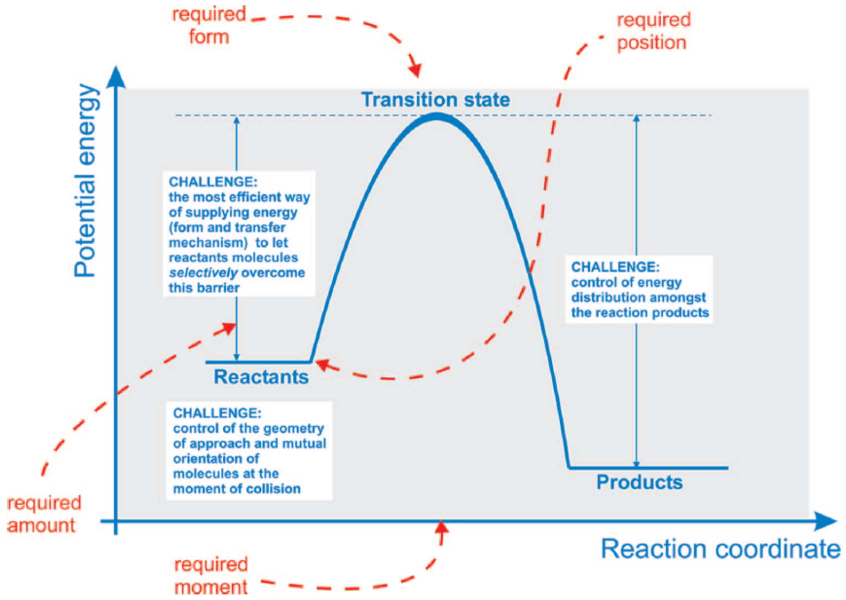
5X reduction in mass
10X reduction in volume
Higher effectiveness

Chemical Process Intensification



Guiding Principles for Process Intensification

- Maximize effectiveness of intramolecular and intermolecular events.
- Give each molecule the same processing experience.
- Optimize driving forces at all scales and maximize the specific surface areas to which they apply.
- Maximize synergistic effects from partial processes.



Tom Van Gerven and Andrzej Stankiewicz (2009). "Structure, energy, synergy, time – The fundamentals of process intensification." *Industrial & Engineering Chemistry Research,* 48(5): 2465-2474.

Symbioses between Modularization and Process Intensification: Mutually Beneficial Linkages

- Smaller process intensification equipment and denser process intensification plant layouts facilitate modularization.

- Module mobility provides advantages:
  - geographically distributed customers/markets
  - energy sources/feedstocks
  - distribution challenges

- Capacity flexibility is possible with module numbering-up.

Background of Case Studies

CASE STUDY 1	CASE STUDY 2	CASE STUDY 3
Specialty chemical driven by manufacturer-operator with the goal of reducing CAPEX	Commodity chemical driven by developer-supplier with the goal of providing cheaper feedstock	Commodity chemical driven by developer-supplier to address storage and distribution challenges

Case Study 1

Case Study 1

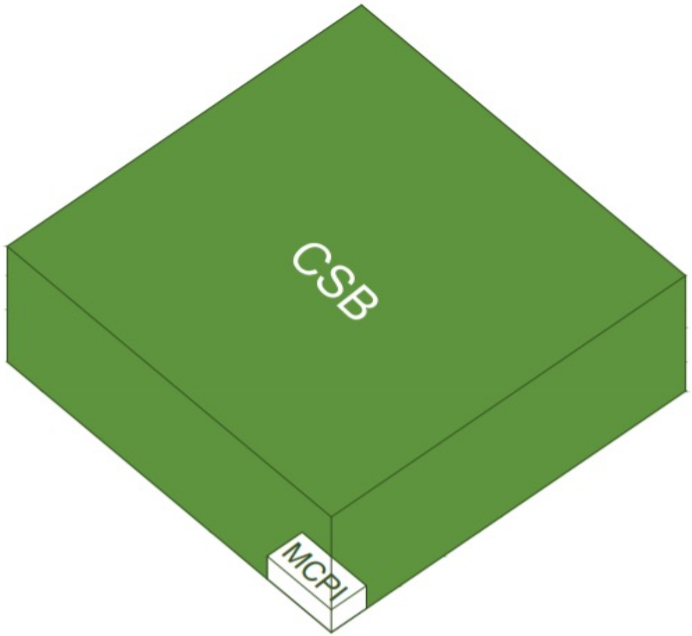
PERSPECTIVE	Manufacturer-operator
GEOGRAPHICAL DISTRIBUTED	Customer
	Specialty chemical
	OTS Tubular RX Batch to Continuous
CLIENT MOTIVATION	Reduced CAPEX
PLANT SIZE REDUCTION	Vol = 250 x
PHASE OF ASSESSMENT	1 year post-Pilot
NUMBERING-UP?	No numbering-up

Specialty Chemical Production

(ISBL) CAPEX-Driver Differences

	Number of modules per train	Height	Brownfield SIMOPS impact
CSB	N/A	30	High
MCPI	1	6	Minimal

Specialty Chemical Production



Site and module footprint

CSB

10,000 ft^2

MCPI

200 ft^2

Specialty Chemical Production

Project Frame and Basis

	Mode	Reactor	Cycle time (hours)	Heat transfer area (ft^2)	Heating time (hours)	Heat loss (kW)	Flushing material (gallons/ batch)	Nitrogen purge (SCF/ batch)	Cooling system
CSB	Batch	12,000 gal. paddle mixer	48	628	10	17	1500	2800	water
MCPI	Continuous	Tubular reactor	N/A	39	N/A	1.2	N/A	N/A	air

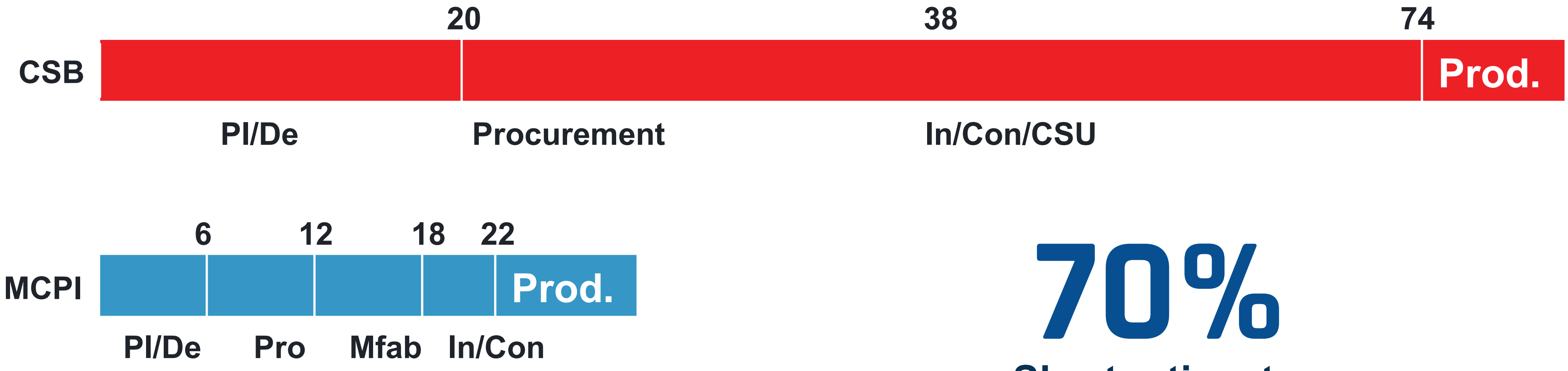
Specialty Chemical Production

CAPEX

	Total Installed Cost	Engineering Cost
CSB	$3,500,000	$350,000
MCPI	$450,000	$55,000

Specialty Chemical Production

Time until Production (weeks)



70%

Shorter time to operations and revenue

Specialty Chemical Production

CAPEX, OPEX, NPV, and Payback Period

CAPEX (USD/MT)

MCPI is 87% lower

CSB: 714
MCPI: 90

NPV

MCPI is 1.9 times higher

PAYBACK PERIOD (MONTHS)

MCPI is 80% shorter

CSB: 12.3
MCPI: 2.5

O&M FTE

MCPI is 91% lower

CBS: 9
MCPI: 0.8

COST OF POWER & UTILITIES

MCPI is 40% lower

CSB: $40 K
MCPI: $24 K

OPEX (USD/MT)

MCPI is 14% lower

CSB: $6.23 M
MCPI: $5.37 M

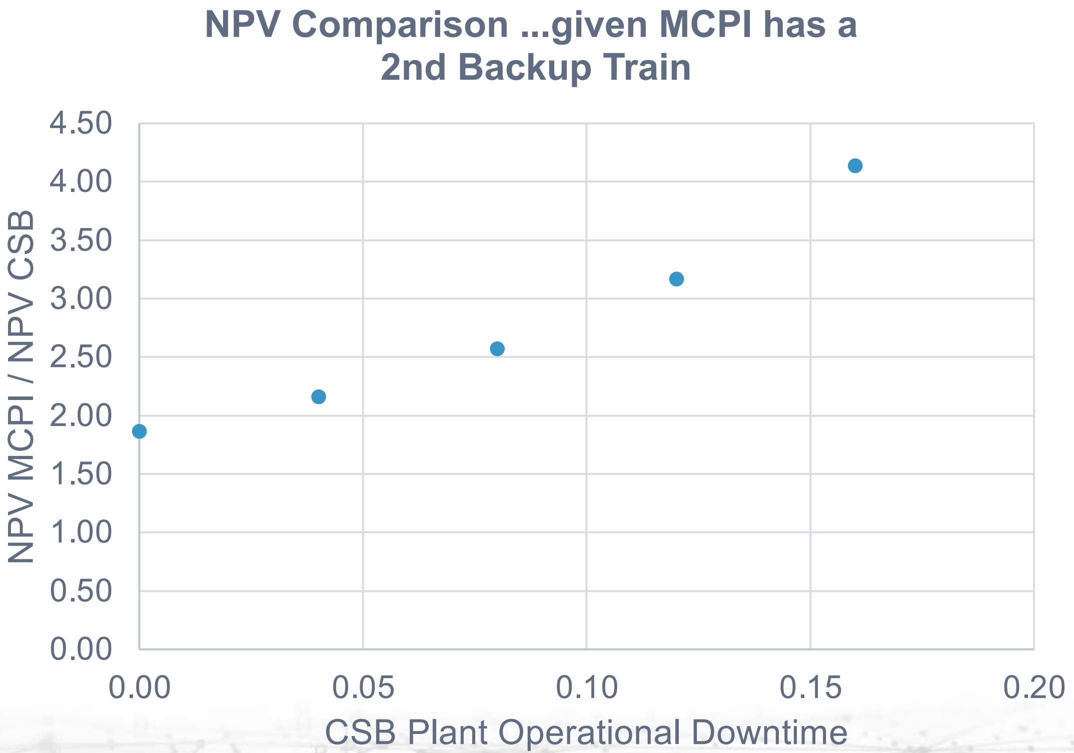
Specialty Chemical Production

Six Top Drivers of Superior MCPI Capital Efficiency:

- PI **equipment** is **smaller, cheaper, and available** off the shelf
- Unit **productivity rate improvements** for module fabrication
- **Pre-shipment testing** of modules enhances **performance assurance**
- **Lower weight** of MCPI means **simpler and lower-cost foundations, support structure**
- **Reduced** module installation time and effort (**SIMOPS**)
- **Earlier recovery of investment** from early production and sales

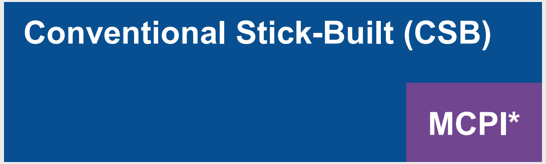
Specialty Chemical Production

Backup MCPI train is a **very attractive option**



Case Study 2

Leveraging Cheap Distributed Energy



Plant Area
(146k MTPY Capacity)

*MCPI has 5 modules within a single train

	Scale-up rate	Footprint	Brownfield SIMOPS impact
CSB	Full capacity in 3 years	141 K	High
MCPI	2X increase in capacity year-to-year	18 K	Minimal

Leveraging Cheap Distributed Energy

Comparison: PI / Process / OPEX Features

Same rated capacity (18,250 MTPY)

Same production rate (76 lbs/min)

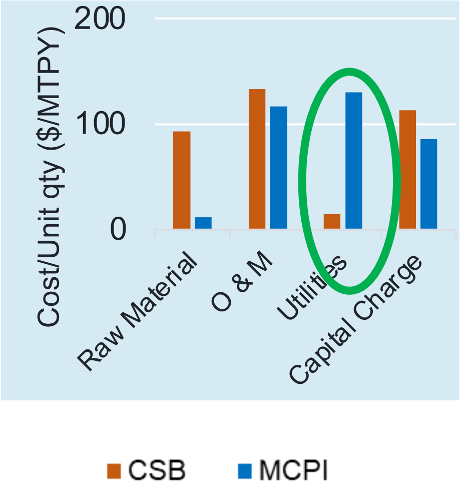
	Raw Material Preprocessing	Waste Management	Operations Staff
CSB	De-sulfurization required	Needs a separate waste management unit	Scales with plant size
MCPI	None	Minimal waste	8 FTE (any # of trains)

Leveraging Cheap Distributed Energy

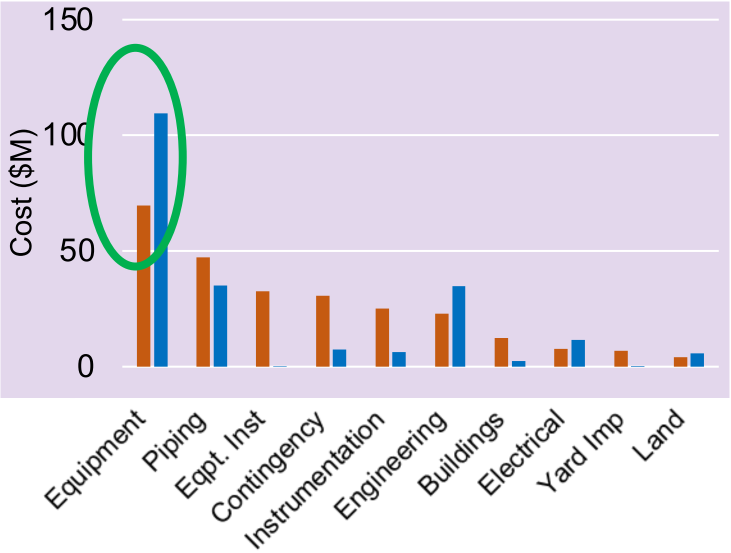
Other Assumptions

	Total Installed Cost (TIC) (1 train = 18,250 MTPY)	Numbering-up Learning Rate	NPV comparison at lifetime of plant (25 years)
CSB	$66M (based on industry data)	80%	Scenario 1: higher Scenario 2: same
MCPI	$44.5M (based on Sievers model)	N/A	

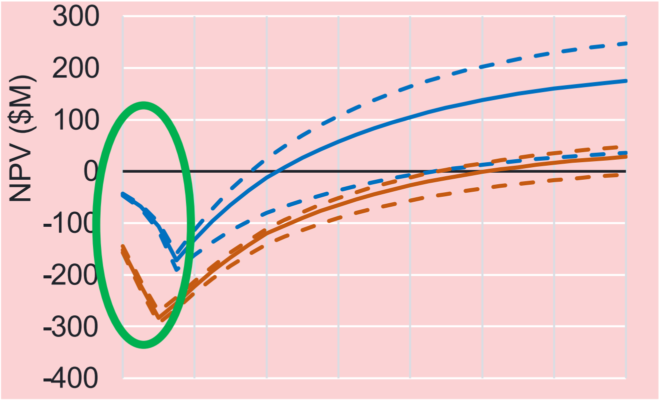
OPEX Cost Breakdown



CAPEX Cost Breakdown



NPV Risk Profile



Utility costs > feedstock gains even with lower utility rates

Lower cost of innovative PI equipment

Faster time-to-market

Leveraging Cheap Distributed Energy

SIX TOP DRIVERS

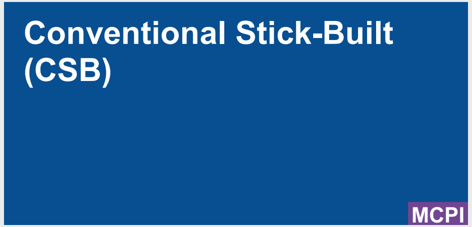
- Increased efforts for engineering of new technologies
- **Higher capital expenditures for new advanced equipment**
- **Reduced time of fabrication of equipment (parallel fabrication, reduced size, piping, etc.)**
- **Lower energy demand (i.e., reduced energy input and losses for reactions)**
- Faster-time to market for new investments; earlier product sales due to shorter processing times
- Economic benefits from earlier completion; Earlier recovery of investment from early production and sales

Key drivers that were NOT indicated as top drivers by the case study partner

Case Study 3

Distributed Commodity Production

CAPEX (ISBL) Features



52X reduction in plant area

	Deployment Schedule	Footprint	Brownfield SIMOPS impact
CSB	Full capacity in 3 years	Smallest 24,000 ft^2	High
MCPI	2x increase in capacity year-to-year	460 ft^2	Minimal

Distributed Commodity Production

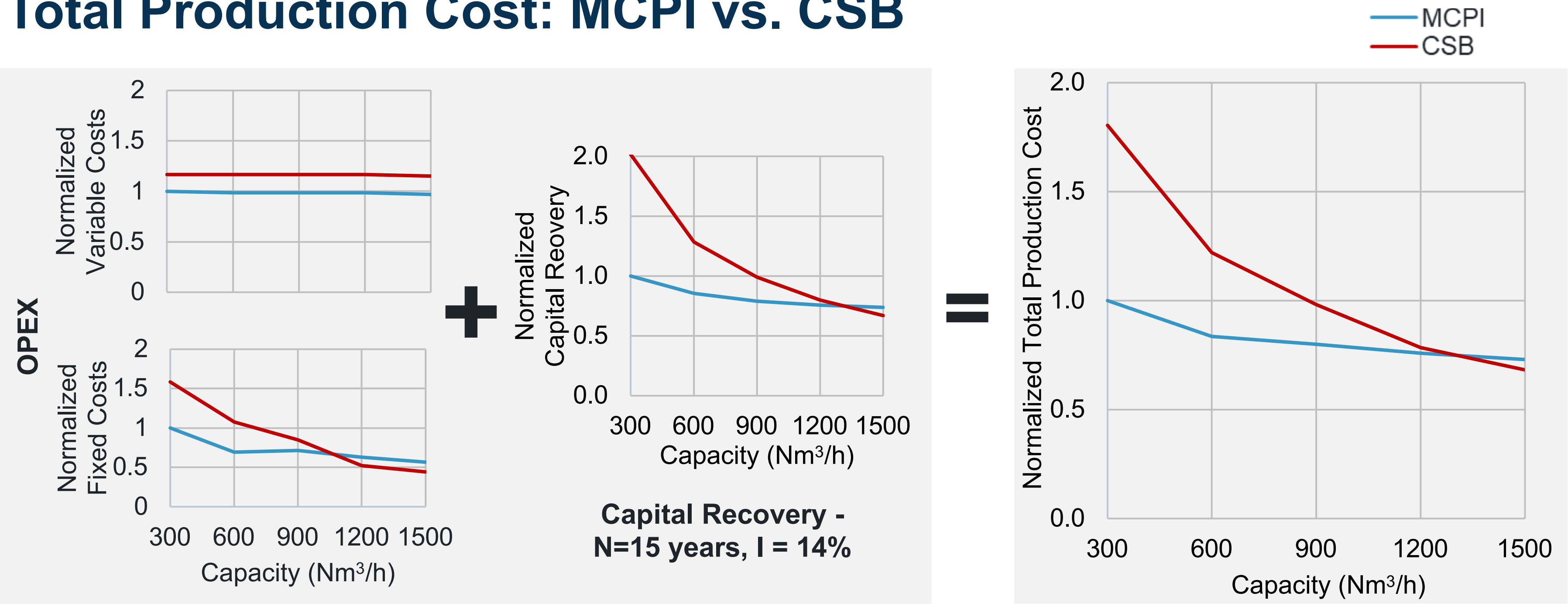
OPEX Features and Other Assumptions

Same rated capacity, 1 train = 11,200 MMSCF (300 Nm^3/h)

Same production rate (244 lbs./min.)

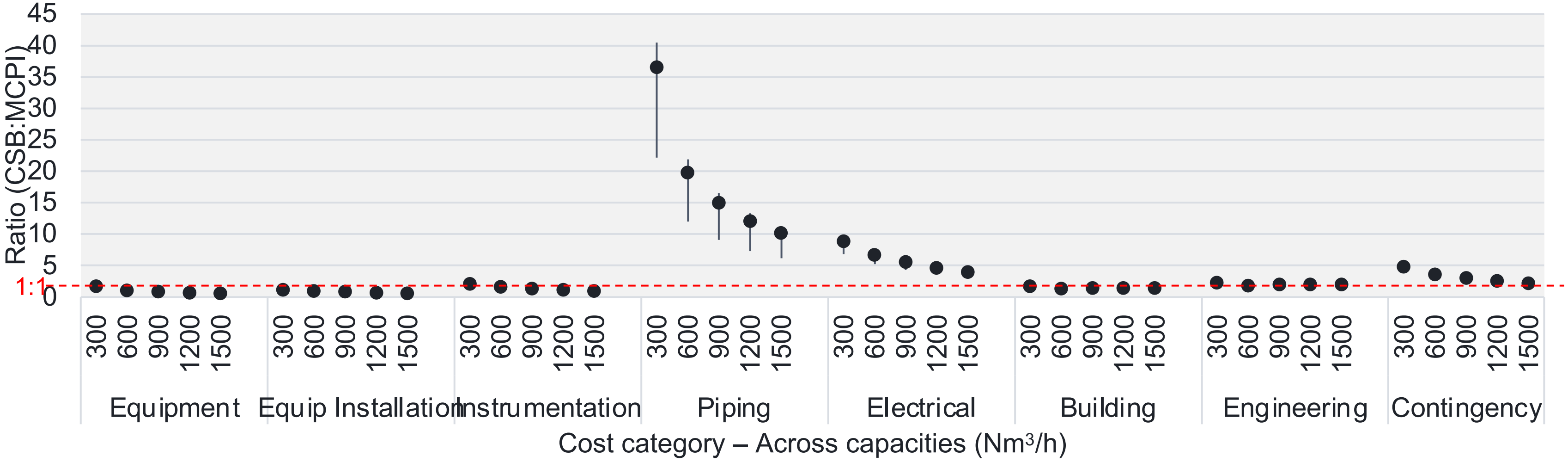
	PI Technology	Operations Staff	Design Maturity	Maximum Numbered-up Skids
CSB	None	Scales with plant size	N/A	N/A
MCPI	Modified reactor and PSA system	1 FTE (1-2 skids), 2 FTE (3-5 skids)	7 years into production (~230+ deployments)	3

Distributed Commodity Production
Total Production Cost: MCPI vs. CSB



- Total production cost for MCPI is relatively lower up to three trains
- Findings align with the case study partner's deployment strategy of numbering-up to three trains; thereafter moving to a mid-sized or a large-sized CSB plant

Distributed Commodity Production CAPEX Comparison (CSB : MCPI)



- **Interconnection systems (piping and electrical)** are the primary drivers for reduced MCPI CAPEX
- Equipment costs for CSB become lower than those for MCPI above a 2-train capacity
- Other costs (engineering, buildings, instrumentation, and contingency) are lower for MCPI relative to CSB – with one exception: instrumentation for a 5-train capacity is greater than for CSB.

Distributed Commodity Production

26 Drivers from the Literature / 6 Top Drivers

- Design effort reduction from DOBM for second, third, fourth, etc. modules
- Reduced CapEx due to reduced number of components
- Module fabricator learning curve benefits from standardization (DOBM)
- Reduced equipment assembly/installation time and labor effort
- PI equipment requires fewer interconnecting systems
- Reduced construction footprint, less land, less infrastructure, etc.

Case Study Key Learnings

1. Conversion from **batch-to-continuous** chemical processing enhances CAPEX reduction and time-to-market
2. **Cost of process intensification technology** is important
3. PI technology can significantly reduce the cost of **interconnecting systems**

Recap / Closure

MCPI challenges old plant design paradigms and offers new opportunities

Substantial benefits may be realized, if managed

Visionary champion is critical to advance MCPI within large organizations

Questions?