2018 FALL LECTURE SERIES

An Introduction to Process Intensification and RAPID Manufacturing

North Jersey Section AIChE

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Hosted by: EI Associates

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  - Olin Hunt – microelectronics chemicals
  - EI Associates – A/E consulting
  - BOC Gases – industrial gases
  - Schering-Plough - pharmaceuticals
  - ALZO International, Inc. – specialty chemicals

ATTRIBUTIONS

Some information presented on these slides was obtained (with permission) from:

- **Realize the Potential of Process Intensification** – James Bielenberg, RAPID Manufacturing Institute, and Michelle Bryner, AIChE, Chemical Engineering Progress, March 2018
- **Modularization in Chemical Processing** – Michael Baldea, et al., Chemical Engineering Progress, March 2018
- **Successfully Implement the Industrial Internet of Things** – Dan Carlson, Emerson Automation Solutions, Chemical Processing, January 2018
- **Simplifying Integration of Modular Projects** – Joy LePree, Chemical Engineering, June 2018

- *…as well as over 35 years of experience in the chemical process industry!*

What we will cover:

- **Introduction to RAPID Manufacturing**
  - *What is RAPID Manufacturing*
  - *What is Process Intensification?*
  - *Advancements in Process Intensification*
  - *A Roadmap to PI Success*
  - *RAPID Jumpstart Projects*
  - *The path forward*
- **The Industrial Internet of Things**
  - *What is the IIoT?*
  - *Drivers of the IIoT*
  - *Benefits of the IIoT*

Process Intensification
and
RAPID Manufacturing

What is RAPID Manufacturing?

- **When it comes to improving energy efficiency and lowering investment requirements in the process industries, modular chemical process intensification (MCPI) has been a long-standing concept. In general, though, MCPI deployment in energy-intensive industries has been limited by several barriers, including:**
  - *Capital costs and RAM (reliability/availability/maintenance) risk involved in committing to new processes*
  - *High complexity of an intensified, modular system, without simplifying standardization techniques*
  - *Insufficient software and design tools and data to develop intensified processes*
  - *Challenge (technical, economic, and re: intellectual property) of developing standardized design and manufacturing protocols for a complex new technology space at an early point in its technical and commercial development*
  - *Limited understanding of design and operation of MCPI technologies across a broad range of key industry participants*

https://www.aiche.org/rapid/about

What is RAPID Manufacturing?

- In December, 2016, the Department of Energy announced the establishment of the 10th Manufacturing USA Institute, representing a critical step in the federal government's effort to double U.S. energy productivity by 2030
- The Rapid Advancement in Process Intensification Deployment (RAPID) Institute is focused on addressing the barriers listed above to enable the development of breakthrough technologies to boost energy productivity and energy efficiency through manufacturing processes in industries such oil and gas, pulp and paper and various domestic chemical manufacturers
- RAPID will leverage approaches to modular chemical process intensification (MCPI) — such as combining multiple process steps like mixing, reaction, and separation into single more complex and intensified processes — with the goal of improving productivity and efficiency, cutting operating costs and reducing waste

https://www.aiche.org/rapid/about

What is RAPID Manufacturing?

(December 20, 2016) The U.S. Department of Energy (DOE) has announced that the Rapid Advancement in Process Intensification Deployment (RAPID) Manufacturing Institute of the American Institute of Chemical Engineers (AIChE) will be the newest, and tenth, member of the nation’s network of Manufacturing USA Institutes.

U.S. Department of Energy Taps AIChE to Lead RAPID Modular Process Intensification Institute

AIChE Rapid team with partners and DOE leaders.

National public-private consortium brings companies, universities, government laboratories and agencies together to take on manufacturing challenge.

What is Process Intensification?

- **As a multidimensional concept, Process Intensification (PI) is not easily defined. Some definitions include:**
  - *Well-known experts in PI Stankiewicz and Moulijn, both at Delft Univ. of Technology, define PI as the development of innovative apparatuses and technologies that bring dramatic improvements in chemical manufacturing and processing, substantially reducing equipment volume, energy consumption, or waste formulation, and ultimately leading to cheaper, safer, sustainable technologies* [(1)]
  - *Stankiewicz and van Gerven add 4 guiding principles to that definition* [(2)]
    1. maximize the effectiveness of intramolecular and intermolecular events
    2. provide all molecules the same process experience
    3. optimize driving forces at all scales and maximize the specific surface areas to which they apply
    4. maximize synergistic effects from partial processes

What is Process Intensification?

- **As a multidimensional concept, Process Intensification (PI) is not easily defined. Some definitions include:**
  - *The **European Roadmap on Process Intensification** describes PI as providing "radically innovative principles (paradigm shift) in process and equipment design, which can benefit (often with more than a factor of two) process and chain efficiency, capital and operating expenses, quality, wastes, process safety and more"* (2)
  - *Reay et al. describe PI as "a chemical and process design approach that leads to substantially smaller, cleaner, safer, and more energy-efficient process technology"* (3)

- **Suffice it to say, a common thread among these definitions is a focus on new schemes and equipment that create improved processes by combining, controlling, and/or enhancing the chemistry and transport phenomena in a chemical process.**

Examples of Process Intensification

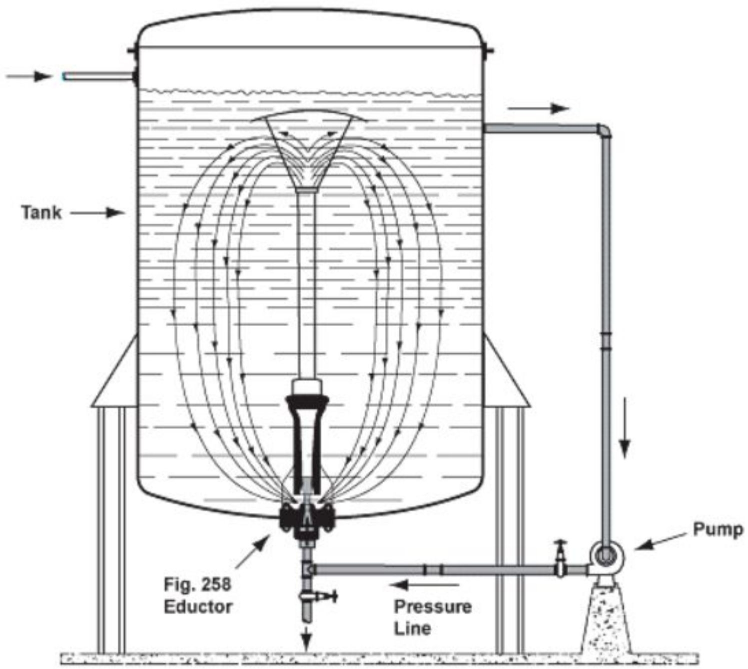
- **The STATIC MIXER:**
- **Although there are many different designs for static mixers, the basic concept is the same:**
  - *Stationary mixing elements placed in the path of fluid flow create locally highly mixed channels for the fluid to move through*
  - *Homogeneous mixing occurs quickly, with no external energy input other than that associated with the small pressure drop, at typically low capital costs*

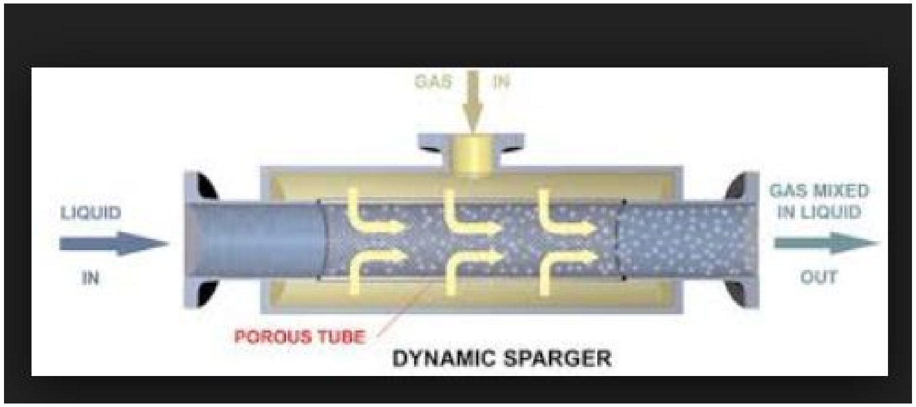
Examples of Process Intensification

- **Static mixers can be incorporated into other unit operations (e.g., reactors) to enable the combination of processes and can be tailored to match mixing scales and times to optimize overall process efficiency, for example:**
  - *static mixers can be placed in a tubular reactor for a two-phase reaction system - creating a high level of mixing while maintaining a largely plug-flow profile (typically found at a much smaller scale) at the larger reactor scale*
  - *Such an approach could offer many advantages over the alternative of operating a large continuous stirred-tank reactor to maintain high levels of mixing.*

Examples of Process Intensification

- **Similar to static mixers are in-line tank eductors and in-line gas spargers. These can improve process efficiency as well as resolve some materials-of-construction issues that can be problematic:**





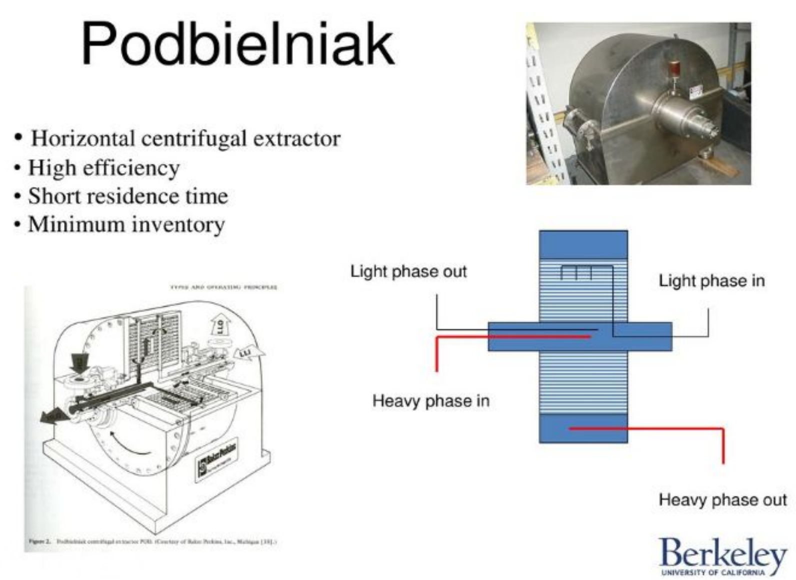
Examples of Process Intensification

- **There are many other examples of PI equipment, including:**
  - *microchannel reactors*
  - *spinning-disk reactors*
  - *centrifugal contactors*
  - *dividing-wall columns*
- **Each of these relies on a novel driving force (*e.g., rotation*) or nonstandard configuration (*e.g., microchannels*) to enable increased control over mixing, reaction, and heat, mass, and momentum transfer to bring about step changes in the reduction of energy consumption and capital costs**

Advancements in PI: Applied Fields

- **While process intensification is still a rapidly developing field that has yet to reach its full potential, many industrial applications of PI have been realized:**
  - *A very early example is the centrifugal separation device patented by Podbielniak more than 70 years ago. The device is still marketed by B&P Littleford, and consists of a horizontal-axis centrifuge that continuously processes liquids for accelerated counter-current solvent extraction and/or liquid-liquid separation.*

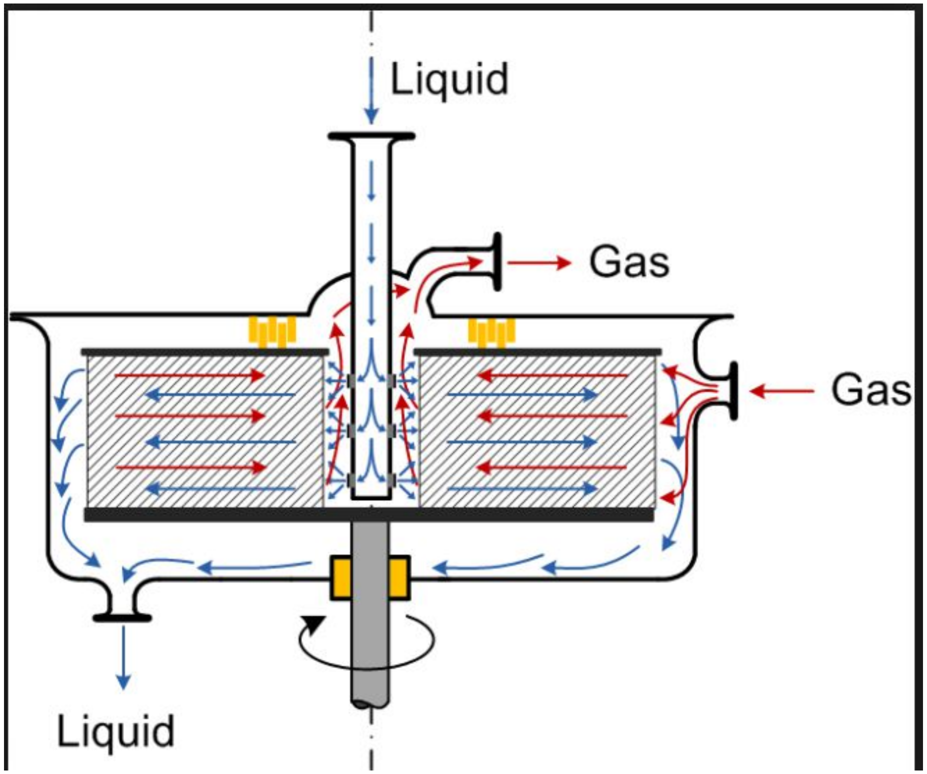
The use of rotation to augment the normal gravity-driven separation of liquid-liquid systems allows for more-compact footprints and improved performance



Advancements in PI: Applied Fields

- **Another example of applied-field-enhanced PI is ICI's development in the early 1980s of the HiGee rotating packed-bed technology, in which a donut-shaped packing rotates to generate a centrifugal force.**

Liquid at the center of the bed sprays outward, and in the presence of high gravity it disintegrates into tiny droplets. The total surface area of the tiny droplets is very high, which significantly improves mass transfer. Gas-liquid HiGee technology has been commercially deployed as an improvement over conventional stripping and distillation



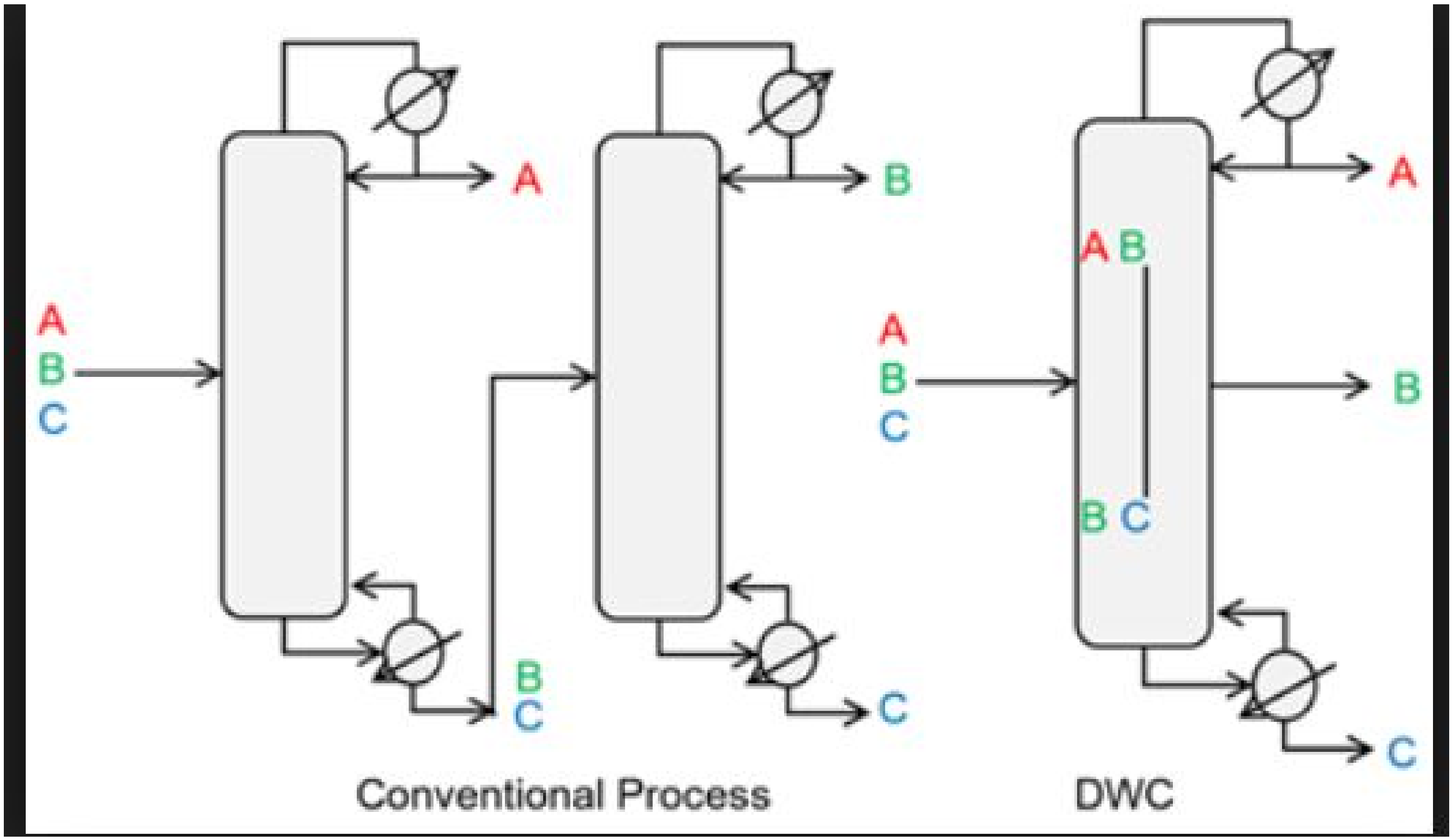
Advancements in PI: Coupled Driving Forces

- **PI has also involved coupling conventional driving forces to reduce the number of process steps required.**
- **One example, dating back to the 1940s, is the dividing-wall column. This device separates a three-phase system in a single distillation tower that incorporates an internal wall into the vessel.**
  - *The wall allows for thermal transfer in the radial direction but restricts mass transfer.*
  - *While dividing-wall columns are not a fit for all separation challenges, in an appropriate process the capital and energy savings can be significant.*
- **Many companies, including BASF, Dow Chemical, and ExxonMobil, have reported successful operation of dividing-wall columns.**

Dividing Wall Column – a closer look

- **The dividing-wall column is one form of process intensification that enables the separation of a three-phase system in a single distillation tower. Very simply:**
  - *An internal wall splits the column into two halves*
  - *The three-phase system is pumped into one side of the column and is reflected by the wall*
  - *The lightest component flows upward and exits at the top of the column, while the heaviest component drops to the bottom and is withdrawn*
  - *The intermediate component is initially entrained in both streams; the intermediate component that flows upward subsequently separates and falls down on the opposite side of the wall, while the component that is entrained in the heavy component separates and flows up the back side of the column, where the entire intermediate stream is recovered through a side port*

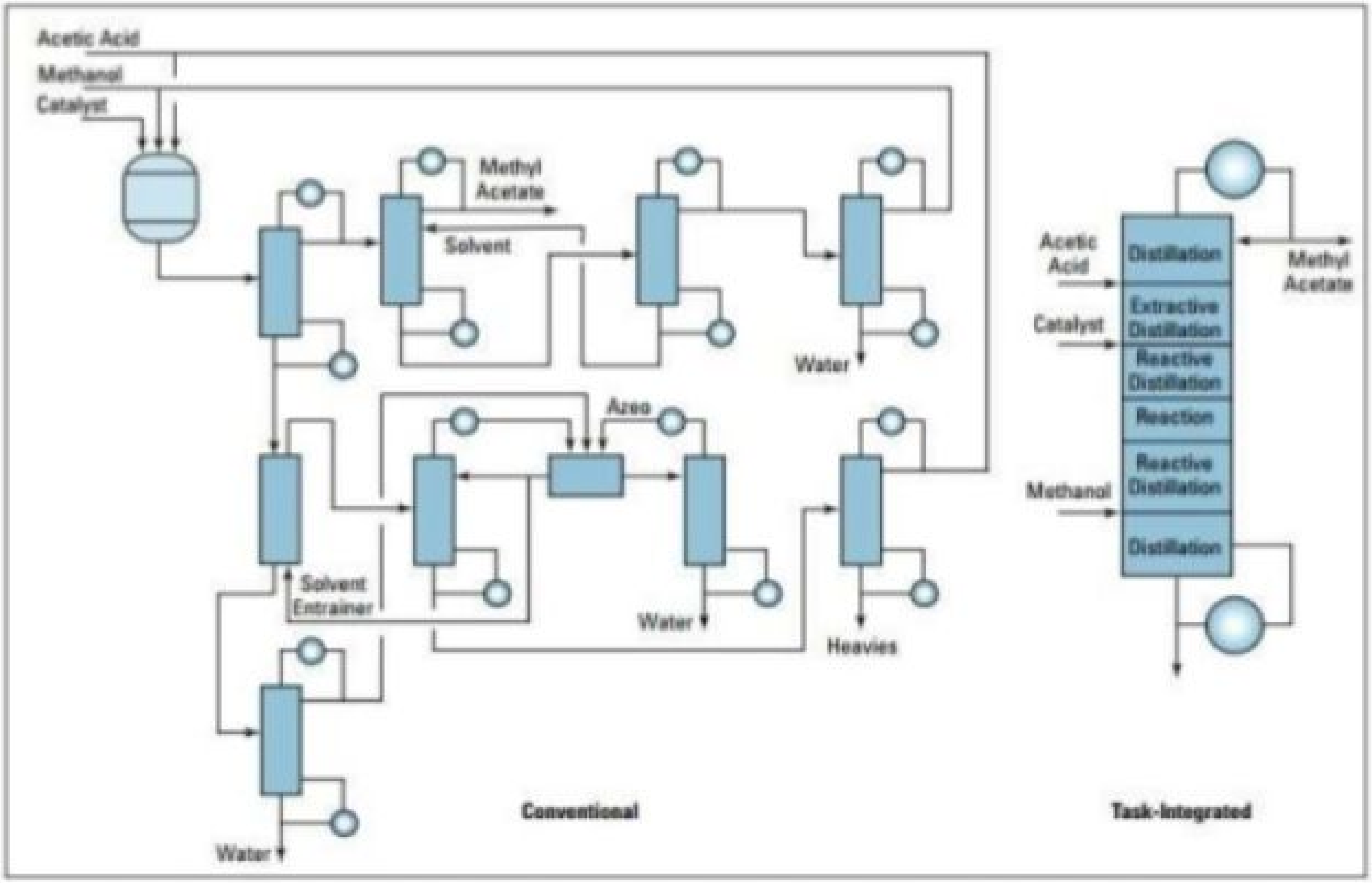
Dividing Wall Column – a closer look



Advancements in PI: Coupled Driving Forces

- **Another example of PI involving coupling conventional functions in unique processing schemes is reactive distillation, which combines separation and reaction in a single unit operation with the general purpose of removing equilibrium limitations.**
- **The most-cited application of reactive distillation *(considered by many to be the archetype of PI in general)* is the methyl acetate process developed by Eastman Chemical**
  - *In Eastman's scheme, five process functions are combined in a single vessel*
- **On an industrial scale, reactive distillation is currently in operation in a variety of processes, including the synthesis of acetates (ethyl, butyl, and methyl), the hydrolysis of methyl acetate, the removal of methanol from formaldehyde, and the formation of fatty acid esters.**

Reactive Distillation



Task-integrated methyl acetate column with comparison to the conventional plant. (Drawing courtesy of Eastman C
(A. Stankiewicz et al.,2000).

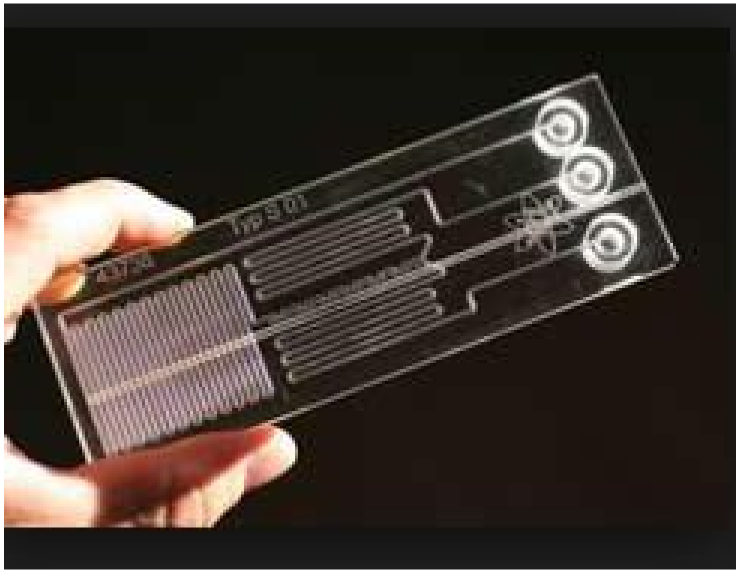
Advancements in PI: Temperature Control

- **Recent activity has focused on modular and micro-channel systems that employ PI concepts.**
- **There have been several commercial attempts to employ microchannel reactors - which allow much higher heat input and removal rates than conventional systems**
  - *to carry out highly endothermic (steam methane reforming) or,*
  - *highly exothermic (Fischer-Tropsch synthesis) reactions at a small scale.*
- **While applications are still limited at this point, activity has shifted from lab-scale equipment to the initial stages of commercial deployment.**

What is a microchannel reactor?

A micro channel reactor is a reactor that consists of numerous channels with small diameters of less than a few millimeters. The micro channel structure provides the following benefits.

- *Higher chemical operation efficiency*
- *Homogeneous mixing*
- *Precise temperature control*
- *Continuous operation*
- *Quick phase separation*



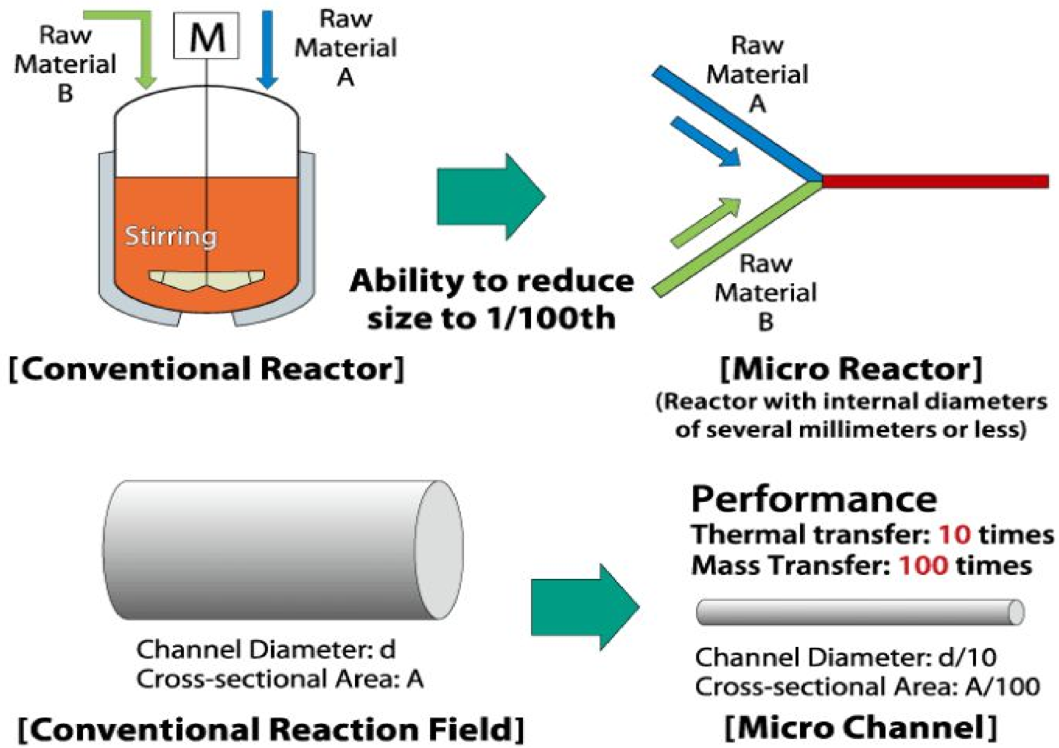
What is a microchannel reactor?

- **Micro channel reactors have been attracting attention due to their excellent thermal and mass transfer performance.**

- **However, micro channel reactors have been applicable only for limited uses, such as the small production of pharmaceuticals and other high value-added goods. One of the issues limiting use is the very limited capacity of micro channel reactors.**

- **Although increasing the number of channels (numbering-up) can be a solution for increasing the capacity, it is difficult to lay out numerous channels (1,000 to 10,000 or more) efficiently in the equipment and distribute fluids to the channels uniformly.**

What is a microchannel reactor?



Heat Transfer: $C_p \Delta T_f \alpha \frac{h}{d}$

Mass Transfer: $t \alpha \frac{d^2}{D}$

C_p: Specific Heat
t: Diffusion Time
D: Diffusion Coefficient
T_f: Fluid Temperature
h: Heat Transfer Coefficient
d: Hydraulic equivalent diameter

Microchannel Photoreactor

Leaf-Inspired Microphotoreactors
Figure 1. The amount of light captured by the microphotoreactors is visible, lit up bright red. As liquid is pumped through thin channels or "veins" in the leaves, light causes the reactions. *Source: Bart van Overbeeke.*

The leaf, made from silicone rubber, can operate in diffuse light. "It can be easily cleaned with some solvent and subsequently reused," says Noel.

"Theoretically, you could use this device to make drug compounds with solar energy anywhere you want," he adds.

The next step is to further improve energy efficiency and increase output.

Artificial Leaf Spurs Energy-Efficient Reactions

Micro photoreactor uses solar energy and microchannels to manufacture pharmaceuticals

By Chemical Processing Staff
Mar 06, 2017

Advancements in PI: Reactive Separation

- **New, commercial concepts for reactive separation are under development**
- **Modular, reactive separation technologies may be a good fit for light-gas conversion, where widely distributed feedstocks and inherent equilibrium limitations on conversion make conventional processing less attractive.**
  - *Example: **CoorsTek Membrane Sciences** in Norway has developed a reactive separation process to non-oxidatively convert natural gas into hydrocarbon liquids. A ceramic membrane incorporated into the reactor simultaneously removes hydrogen and injects oxygen, which enables gas-to-liquids conversion in one vessel*

Process Intensification: A Roadmap to Success

- **Making real strides in PI will require the collaborative efforts of diverse stakeholders to address complex and crosscutting gaps. The RAPID Manufacturing Institute has worked with over 100 subject-matter experts from across its member base to develop a roadmap that identifies high-priority gaps that, if addressed, would significantly impact the success of PI in manufacturing:**

Process Intensification: A Roadmap to Success – Modeling Tools

- **The lack of readily available modeling tools is a major barrier to widespread development and deployment of PI. As new technologies and design schemes are developed, engineers will need a way to evaluate and screen these ideas**
  - *Models and simulation tools similar to those available for conventional technologies are needed to evaluate PI processes, including integrated processes (such as reaction and separation) and cyclic processes (such as pressure-swing adsorption and temperature-swing adsorption).*
  - *These models should be able to calculate heat and material balances for PI as well as conventional process technologies so engineers can analyze and compare hybrid process schemes*
  - *While specialized modeling tools already exist for a few PI applications, the development of tools that address a larger set of technology options and that are accessible by a broader community of users would be a major step forward.*

Process Intensification: A Roadmap to Success – Available Data

- **Along with modeling and simulation tools, data for PI systems is also lacking and will be needed for the development and evaluation of new technologies**
  - *Unlike traditional processes, for which data on the thermodynamic properties of bulk species is sufficient, intensified processes will require data describing the interactions between the chemicals of interest and other complex materials, such as novel solvents or mass-separating agents*
  - *The lack of physical property data for these complex systems is a critical gap that must be filled*

Process Intensification: A Roadmap to Success – Standard Designs

- One way of applying PI to energy-intensive manufacturing sectors is to use modular subsystems and intensified components that are preassembled then transported to and installed at a manufacturing site. Such modules would enable decentralized manufacturing and a numbering-up strategy

- Although the potential benefits of modular manufacturing are well-established, several barriers have prevented wide-scale deployment. Perhaps the most significant of these has been the custom nature of modules, which makes them difficult and costly to design and install

- Defining uniform design approaches and standardized pieces of equipment could enable modular manufacturing to realize the "scale-out/number-out" economics required to make this approach viable.

Process Intensification: A Roadmap to Success – New Process Schemes

- **Integrating multiple unit operations into a single device is a classic illustration of process intensification. In particular, many see the combination of reaction and separation as a PI technology that could have a large impact**

- **Membrane-enhanced and sorption-enhanced reactors are examples of this approach**
  - *Developing such integrated reactive separation technologies along with the requisite advanced materials (e.g., membranes that can operate at high temperatures) could transform the production of many commodity chemical*

RAPID Manufacturing Institute: 2018 Jumpstart Projects

- **On Aug 27, 2018 the RAPID Manufacturing Institute announced its 2018 projects selected for funding. Bill Grieco, RAPID's CEO, stated,**

  "The selection process was highly competitive. We received 48 comprehensive submissions that not only addressed our technical focus areas but also reflected our education and workforce development goals. Ultimately, we selected eight (8) new projects for funding, adding to our current portfolio of 25 projects which already deploy over $30 million in public-private investments. These. new projects further RAPID's mission to promote process intensification (PI) in the chemicals, oil and gas, and pulp and paper industries."

  CTO Jim Bielenberg added, *"Not only do the projects selected contribute to our focus areas but also offer novel approaches and real costs savings for industry if commercialized and implemented."*

Technical R&D Projects

- **Modular Catalytic Partial Oxidation Reactors using Microstructured Catalyst Structures with Combined High Thermal Conductivity and Flame Extinction to Enable High Per Pass Conversion of Non-Diluted Reactants Above the LEL**
  - *Partner Organizations – Auburn University, IntraMicron, Scientific Design, and MATRIC*
  - ***Project Summary**: This project plans to use IntraMicron's platform technology of microfiborous entrapped catalysts (MFEC) to create a safer and more efficient process for the production of ethylene oxide.*

- **High Purity Ethanol Without Distillation: Carbon Nanotube Enabled Ethanol Dewatering**
  - *Partner Organizations – University of Connecticut (UConn), Mattershift and Fraunhofer USA*
  - ***Project Summary**: This project will use a carbon nanotube (CNT) membrane to selectively extract biofuel, in this case ethanol, from a broth stream.*

Technical R&D Projects, cont'd

- **Use of Power Ultrasound for Non-thermal, Non-equilibrium Separation of Ethanol/Water Solutions**
  - *Partner Organizations – University of Illinois at Urbana-Champaign (UIUC), Carnegie Mellon University, Archer Daniels Midland, Flint Hills Resources*
  - ***Project Summary**: This project proposes to develop, test, and demonstrate a continuous-flow, scalable, nonthermal, nonequilibrium liquid separation for the test case of ethanol + water that uses ultrasound, and avoids the heat transfer losses and azeotropic bottleneck of distillation.*

- **On Demand Treatment of Wastewater Using 3D Printed Membranes**
  - *Partner Organizations – University of Pittsburgh, Lubrizol, Siemens*
  - ***Project Summary:** This project will demonstrate on demand separation of multicomponent and multiphase water oil mixtures using 3D-printed membranes.*

Technical R&D Projects, cont'd

- **Modular Mechanical Vapor Compression Membrane Distillation (MVC-MD) for Treatment of High TDS-Produced Water**
  - *Partner Organizations – Texas Tech University, University of Arkansas, Apache, W.L. Gore*
  - ***Project Summary**: This projects aims to integrate mechanical vapor compression (MVC) with membrane distillation (MVC-MD) to intensify the treatment process for produced water from hydraulic fracturing of shale oil and gas.*

- **Deploying Intensified, Automated, Mobile, Operable, and Novel Designs "DIAMOND" For Treating Shale Gas Wastewater**
  - *Partner Organizations – Texas A&M University, University of Pittsburgh, University of Texas at Austin, U.S. Clean Water Technology*
  - ***Project Summary:** This project is focused on developing integrated design and operating approaches for modular systems that can be deployed in the treatment of flowback and produced water resulting from shale gas production.*

Education and Workforce Development

- **Modular Chemical Process Intensification (MCPI) Boot Camp at the Advanced Technology and Manufacturing Institute**
  - *Partner Organization – Oregon State University*
  - ***Project Summary**: Oregon State will develop a 4-day "boot camp" for professional engineers interested in advancing MCPI in the chemical industry.*

- **RAPID Integrated Course: Emerging Membrane Processes for Water Purification**
  - *Partner Organization – University of Arizona with support from Chemstations*
  - ***Project Summary**: The University of Arizona will develop a 4-day face-to-face course enabling both professional engineers and graduate students to compare and contrast the uses of conventional membrane processes over emerging membrane processes in order to purify water.*

The Path Forward

- The advantages of PI over conventional process optimization strategies are undeniable. While progress has been made in advancing several aspects and design schemes of PI, there is much more potential to be exploited

- In the coming months, the RAPID Manufacturing Institute will start 21 new projects that address many of the manufacturing issues already identified and will also open its second call for projects

- The institute is also advancing a suite of educational offerings to help researchers and practicing engineers learn process intensification and modular processing concepts that they can apply to issues occurring within the chemical and commodity manufacturing space

- For more information about RAPID and how to get involved, go to www.aiche.org/rapid

The Industrial Internet of Things (IIoT)

The Industrial Internet of Things

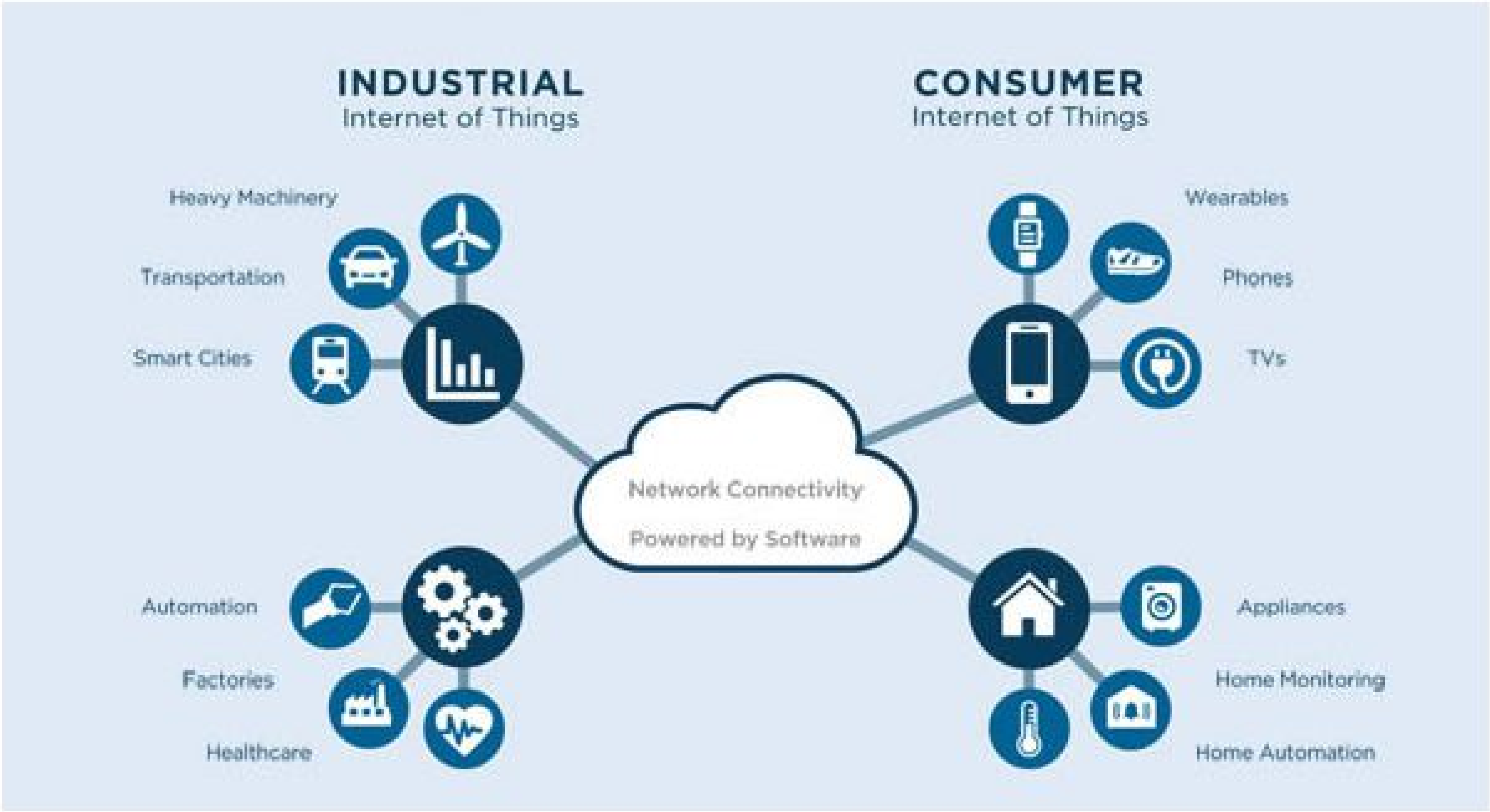
- **What is the Industrial Internet of Things (IIoT)?**
  - *Initially, the Industrial Internet of Things or IIoT, mainly referred to an industrial framework whereby a large number of devices or machines are connected and synchronized through the use of software tools and third platform technologies in a machine-to-machine and Internet of Things* context*
    - » **** a.k.a., Industry 4.0 or Industrial Internet context***
  - *Today it is mainly used in the scope of Internet of Things applications outside of the consumer space and is about applications and uses across several sectors, to distinguish between consumer Internet of Things applications and business/industry applications.*
  - *The Industrial Internet of Things is defined as “machines, computers and people enabling intelligent industrial operations using advanced data analytics for transformational business outcomes”.*

The Industrial Internet of Things

- **The Industrial Internet of Things is part of the Internet of Things**
  - *The Internet of Things (or IoT) is data-rich: large amounts of data get collected, aggregated and shared in a meaningful way*
  - *The goal is to increase the automation level at domestic and commercial levels*
  - *Change human tasks where automation leads to a decrease of specific types of work but at the same time requires new skillsets*
  - *The goal of the Industrial Internet of Things is also not to fully replace human work, but to enhance and optimize it*
    - » *E.g., creating new revenue streams and business models with a big role for data analysis*

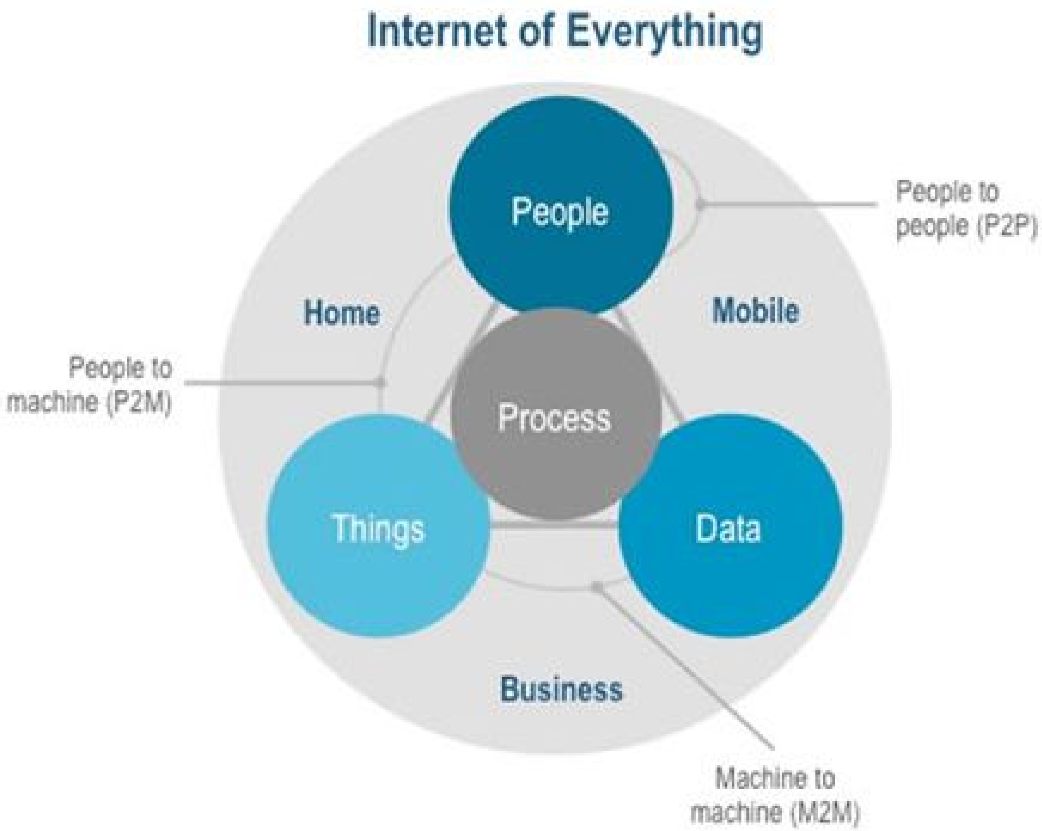
- **Benefits of the Industrial Internet of Things in manufacturing and beyond**
  - *One of the greatest benefits of Industrial Internet of Things has to be seen in the reduction of human errors and manual labor, the increase in overall efficiency and the reduction of costs, both in terms of time and money. We also cannot forget the possible underpinnings of IIoT in quality control and maintenance.*

The Industrial Internet of Things vs the Consumer Internet of Things



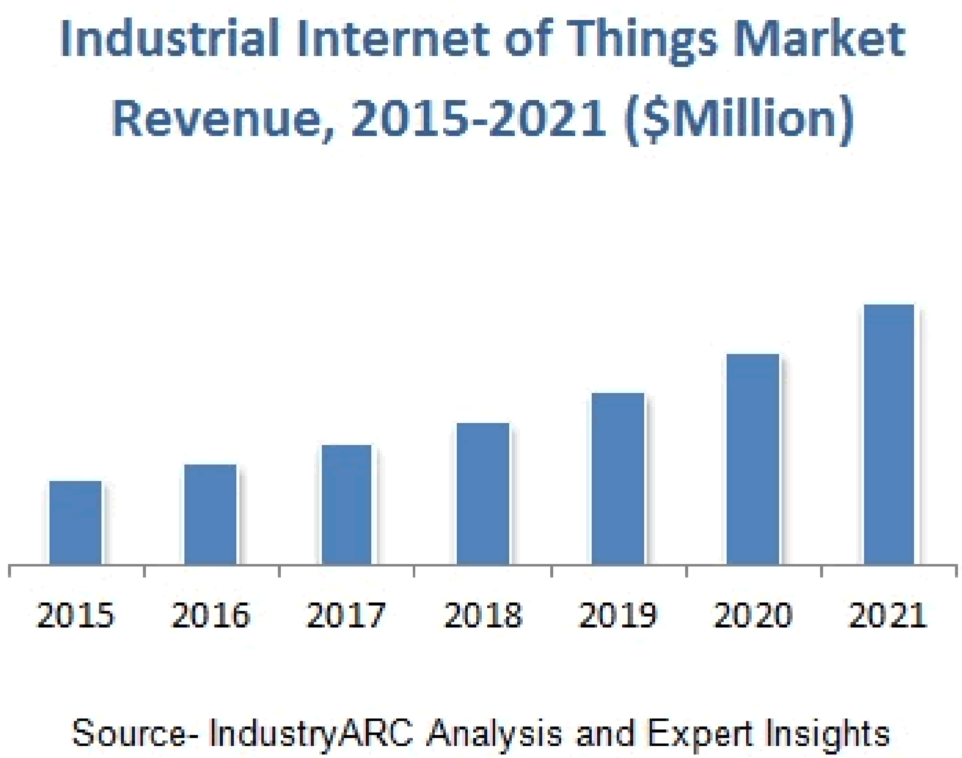
The difference between the Industrial Internet of Things and Consumer Internet of Things as depicted by Vector Software – source – courtesy Vector Software

IIoT's Relationship to the Internet of Everything



The place of machine-to-machine or M2M in the Internet of Everything view of Cisco – source Cisco

Market Revenue Trend of the IIoT



Industrial Internet of Things revenue – source IndustryARC Analysis and Expert Insights

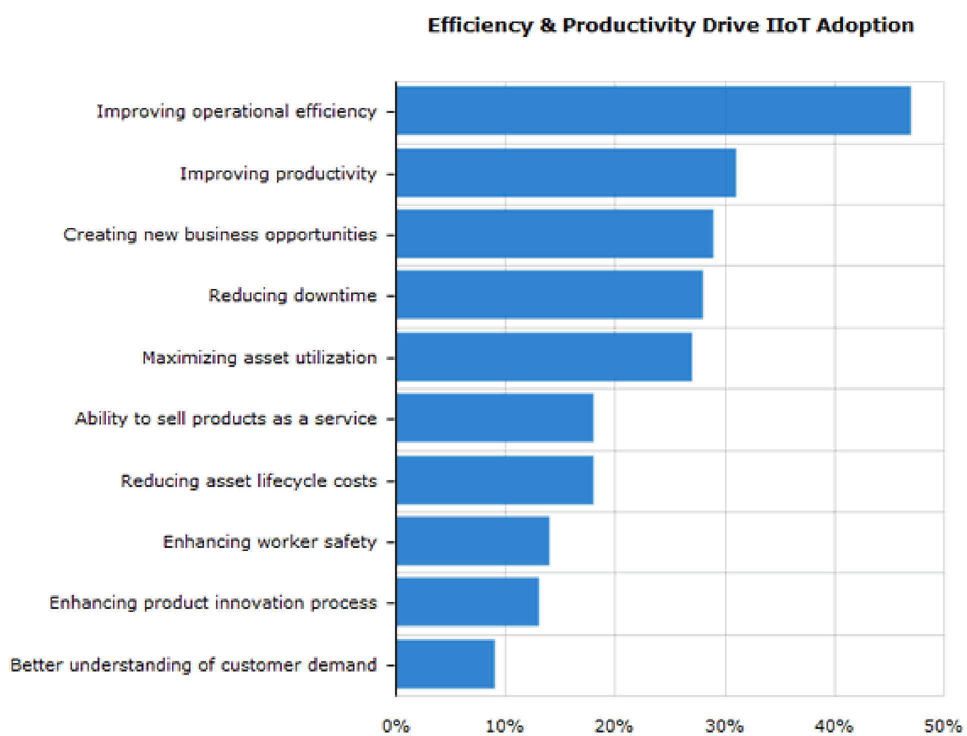
Benefits of the Industrial Internet of Things

- **An intelligent communication loop set up between machines enables timely attention to maintenance issues minimizing downtime and lost productivity**

- **The safety level of the operations can be boosted by alleviating the risk factors**
  - *The Industrial Internet of Things enhances the benefits of the Internet of Things, offering significant benefits to the industries where human error could result in massive risks*
  - *Moreover, the Industrial Internet of Things is and can be used to reduce the exposure of the human workforce to scenarios with high industrial hazard potential*

Benefits & Drivers of the Industrial Internet of Things

- **The Industrial Internet of Things is likely to force more unified device protocols and architectures that will allow machines to communicate seamlessly and thereby enhance interoperability.**



Sources: Morgan Stanley-Automation World Industrial Automation Survey, AlphaWise

Machine-to-machine communication & the IIoT

- **In the pure machine-to-machine (M2M) context, the advantage of the frameworks and systems that the Industrial Internet of Things refers to, is that they can operate semi-independently or with very minimal human intervention.**
  - *Such systems will increasingly be able to intelligently respond and even change their course of action based on the information received through the feedback loops established within the framework*
  - *The key is **machine-to-machine communication** (M2M), which is an element of the Internet of Things but also refers to specific activities and to the initial stages of the Industrial Internet of Things*
- **The idea behind machine-to-machine communication is to reduce human interventions as much as possible so that the highest level of automation could be achieved.**

Implementation Challenges

- **Technology**
  - *There are many technical buzzwords, and some vendors may say they can solve all your technical problems. However, what's right for your organization?*
  - *Can you leverage any of your existing infrastructure?*
- **Networking**
  - *What things should you use IIoT to connect, and how?*
  - *Will these connections be secure?*
  - *How does this change the Purdue Model (the hierarchical architecture of information flow in an enterprise)?*
    - ***Purdue Enterprise Reference Architecture** (PERA) is an 1990s reference model for enterprise architecture, developed by Theodore J. Williams and members of the Industry-Purdue University Consortium for Computer Integrated Manufacturing*

The Purdue Model

Implementation Challenges cont’d

- **Organization**
  - *Many IIoT projects span areas handled by operation technology (OT) and information technology (IT) groups. How do you leverage the benefits of automation for the entire organization by getting these groups to work together?*
- **Sustainability**
  - *How do you start small while still preserving scalability?*
  - *How do you maximize uptime?*
  - *How do you maintain the system?*
- **Business Case**
  - *How do you justify infrastructure, applications and change management by showing a positive bottom-line impact?*

Cost Justification

- **Typically, one or two key applications can justify an initial IIoT infrastructure installation - and reduce the cost of implementing subsequent applications**

- **For example, suppose a plant must monitor 100 pressure relief valves (PRVs) for compliance but has no wireless instrument infrastructure**
  - The typical cost of a wired installation is $18,000 per point while a wireless implementation is $3,000 per point, which includes adding the wireless infrastructure
    - » *The cost for wireless PRV monitoring breaks down to about one-third for wireless acoustic instruments to detect valve lifts and two-thirds for the new wireless infrastructure*
  - Opting for wireless would result in ***$1.5 million in project savings*** ($1,800,000 versus $300,000), or even more if the wireless infrastructure spending is amortized over other projects

Typical Returns on Investment

TYPICAL RETURN ON INVESTMENT

Application	Real-time Insight	Annual Savings, $ millions	Implementation Cost, $ millions	ROI, months
Heat exchanger monitoring	Fouling and efficiency	2.7–3.6	0.62	3
Cooling tower monitoring	Efficiency and health	0.3–0.5	0.16	4
Steam trap monitoring	Energy waste and water hammer risks	2.5–3.3	1.48	5
Relief valve monitoring	Emissions and leaks	2.4–3.2	1.59	6
Pump monitoring	Cavitation and pump health	0.5–0.6	0.55	11
Air-cooled heat exchanger monitoring	Fan health and fouling	0.9–1.1	1.20	13
Mobile workforce	Startup and turnaround efficiency	1.6–2.1	0.40	3
Safety shower and eye wash monitoring	Instant trigger notification	per incident	0.39	*
Total		10.9–14.4/year	6.39 one time	5

* For safety rather than ROI.

Table 1. A medium-size chemical plant or refinery typically can find a variety of initiatives offering fast payback.

Source: ***Successfully Implement the Industrial Internet of Things*** – Dan Carlson, Chemical Processing, January 2018

Cost Justification

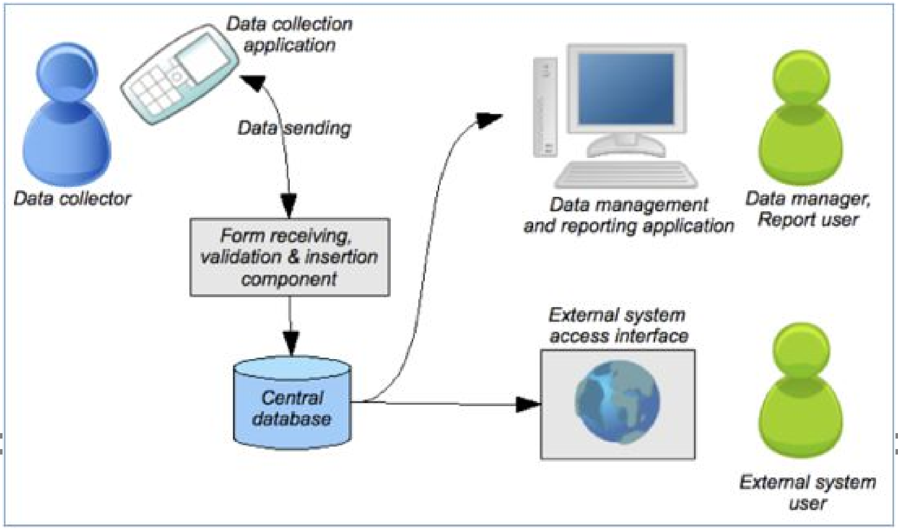
- **Now suppose the PRVs are scattered across the site and providing proper coverage requires ten wireless gateways, each of which can connect up to 100 wireless instruments?**
  - *The wireless option not only saves $1.5 million for the initial project but also provides 900 spare input/output (I/O) points for other applications.*
  - *If the wireless infrastructure already existed, project cost would drop dramatically, primarily involving installing additional wireless instruments, plus some small amount for integrating the information from these instruments into the control and monitoring systems.*
  - *In general, a wireless project typically costs 25% less and takes only 25% of the time of one using a traditional wired approach*
  - *Additionally, these wireless projects provide the foundation for an IIoT implementation, as they automatically supply data previously inaccessible due to cost.*

Cost Justification

- **Annual savings realized by wireless applications actually accrue in several key areas**
  - *lower cost for compliance*
  - *increased production*
  - *reduced maintenance expenses*
  - *decreased exposure to hazardous environments*
  - *and more productive use of staff (by switching personnel from routine inspections to higher-value work).*
- **Once annual savings are estimated, the next step is calculating costs.**
  - *The calculation process starts by understanding the requirements and costs for each application*
  - *From these, you can develop general infrastructure requirements that will include leveraging existing infrastructure as well a adding infrastructure as appropriate*
  - *The key is a method to see the common requirements and features across many applications for different functional groups in the plant such that the value and costs can be shared.*

Additional Benefits

- **For the chemical plant example, the monitoring of 100 PRVs was the key driver, initiated by a request from the Health, Safety, Security and Environmental (HSSE) group to comply with new regulations**
  - *A wireless infrastructure consisting often Wireless HART gateways was installed, and data from the 100 wireless acoustic transmitters monitoring the PRVs were routed to a PRV app residing on a server*
  - *HSSE personnel now receive alerts and data for corrective action and environmental reporting*

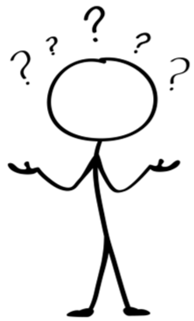


Additional Benefits, cont’d

- **Process engineers, seeing the value gained by the HSSE and reliability groups, decided to better monitor the health of compressors and large heat exchangers**
  - *Data had been collected manually from pressure gauges and with local measurements of heat*
  - *Wireless instruments were installed to measure pressure and temperature, replacing manual rounds*
  - *The data from these instruments were combined with existing data in the plant's historian and sent to the facility's asset-class analytics software (e.g.,Plantweb Health Advisor applications), which contain pre-made analytics and dashboards*
  - *As a result, the plant now can see overall health metrics, which are correlated with production and used to generate work orders that go to the existing CMMS system*

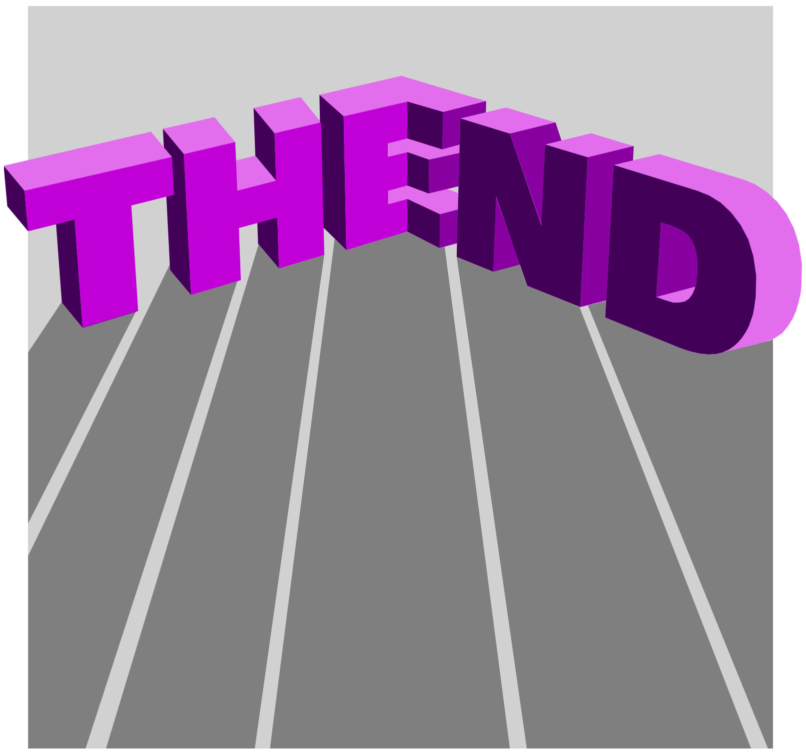
Additional Benefits, cont’d

- **The reliability group - prompted because monthly vibration inspections didn't suffice to prevent failure of critical rotating equipment - then started an initiative for more-proactive monitoring**
  - *This involved adding wireless vibration transmitters and routing data from these instruments to an existing asset management system previously used to store data from manual rounds*
  - *Data became available in relevant time, once every few seconds instead of after each round*
  - *Some manual inspections still took place, but less frequently.*
- ***And the list goes on………………***



In Summary

- **To summarize, here are some of the key benefits of IIoT in an industry context**
  - *Improved and intelligent connectivity between devices or machines*
  - *Increased efficiency*
  - *Cost savings*
  - *Time savings*
  - *Enhanced industrial safety*


THE END

"There is no expedient to which a man will not resort to avoid the real labor of thinking."

Sir Joshua Reynolds

THANK YOU

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