PROCESS INTENSIFICATION: TOWARDS AN EFFICENT AND SUSTAINABLE SOCIETY

26TH PROCESS INTENSIFICATION MEETING, THE BEEHIVE, NEWCASTLE UNIVERSITY

February 16th 2018

BITS Pilani
K K Birla Goa Campus

Prof. Srinivas Krishnaswamy
Department of Chemical Engineering

This presentation is not meant to belittle any work done in the area of PI. It acknowledges the efforts of several researchers and merely aims to provide my personal perspective in this all important area and possible roadblocks which need to be addressed to achieve greater success

Prof. Srinivas Krishnaswamy
Professor

Educational Qualifications
B.E. (Chemical), Shivaji University, 1991
PhD, University of London, 2004

Work Experience
- **Production Engineer,** Oswal Petrochemicals (1991 – 1993)
- **Scientific Officer,** Bhabha Atomic Research Centre (1993 – 1999)
- **Post- Doctoral Research Assistant,** University of Sheffield, UK
- **Assistant Professor,** BITS Pilani Goa, 2005 – 2010
- **Associate Professor**, 2010 – 2015
- **Professor**, 2015 – till date
- **Visiting Professor,** Lunghwa University of Science and Technology (May – July 2009)

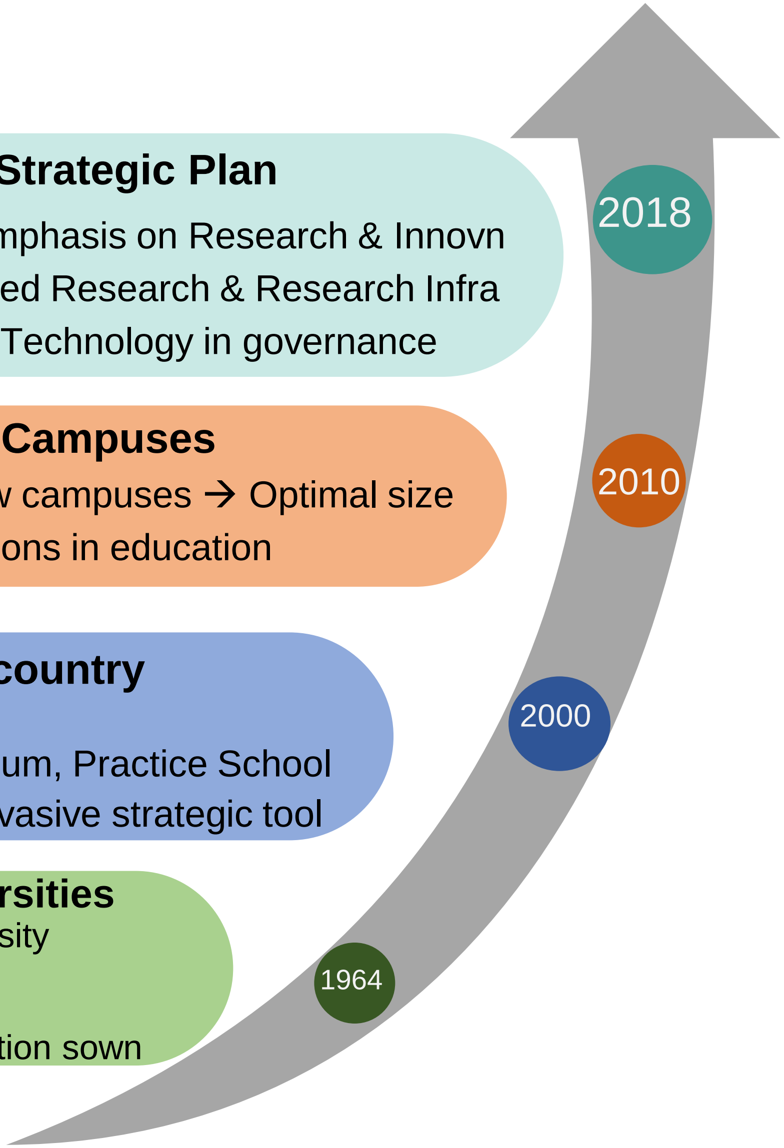
Research interests: Addressing challenges posed in developing practical cost effective, energy efficient and environment friendly systems from a commercialization point of view (Unmixed Combustion, Coke reduction in reactor systems, desalination)

PhD supervision: 6 (1 completed, 5 on-going) **Research Projects:** 7 Projects (~ 718.3 lakhs)

Teaching Interests: Chemical Engineering thermodynamics, Kinetics and reactor Design, Numerical Methods for Chemical Engineers, Process and product Design

Website URL: **http://universe.bits-pilani.ac.in/goa/srinivas/profile**

BITS PILANI THE JOURNEY



Focus on Research, Vision 2020, Strategic Plan

- Transform as an Inst with far greater emphasis on Research & Innovn
- More HD Programs; growth in Sponsored Research & Research Infra
- Aggressive faculty recruitment targets; Technology in governance

Expansion, Optimum Scale: New Campuses

- Began expansion, within Pilani and new campuses → Optimal size
- Consolidated gains; Continued innovations in education

A Top Teaching Institution in the country

- Growth of Pilani Campus
- New Programs & Innovation in Curriculum, Practice School
- Shaped *Industry Engagement* as a pervasive strategic tool

One of the early Deemed to be Universities

- Earlier 3 colleges under Rajasthan University
- Visionary Founder Shri G D Birla
- Ford Foundation Grant, MIT Collaboration
- Seeds for a culture of innovation in education sown

Contents

Process Intensification! What is it?

- Involves addressing challenges posed in **developing & sustaining** practical cost effective, energy efficient and environment friendly systems from a commercialization point of view, thereby attempting to bridge the gap between **know-why and know-how**.
- Converting yesterday / today's Science into tomorrow's Engineering / Technology
- Targets dramatic improvements in manufacturing and processing by **rethinking existing** operation schemes into ones that are both more **precise** and **efficient** than existing operations.

Chemist perspective

↓

Every molecule has the same processing experience

Chemical Engg. perspective

↓

It is all about enhancement

What does PI offer?

- Capital investment reduction
- Energy use reduction
- Raw material cost reduction
- Increase process flexibility and inventory reduction
- Ever greater emphasis on process safety
- Increased attention to quality
- Combining separate unit operations in one equipment
- Enhance mixing, improve heat and mass transfer, Raw material cost reduction, reaction kinetics, yield and selectivity
- Reduction in process complexity
- Better environmental performance

ANY CHEMICAL ENGINEERING DEVELOPMENT THAT LEADS TO SUBSTANTIALLY SMALLER, CLEANER, SAFER AND MORE ENERGY EFFICIENT TECHNOLOGY IS PROCESS INTENSIFICATION

Smaller = safer?

So is smaller safer?

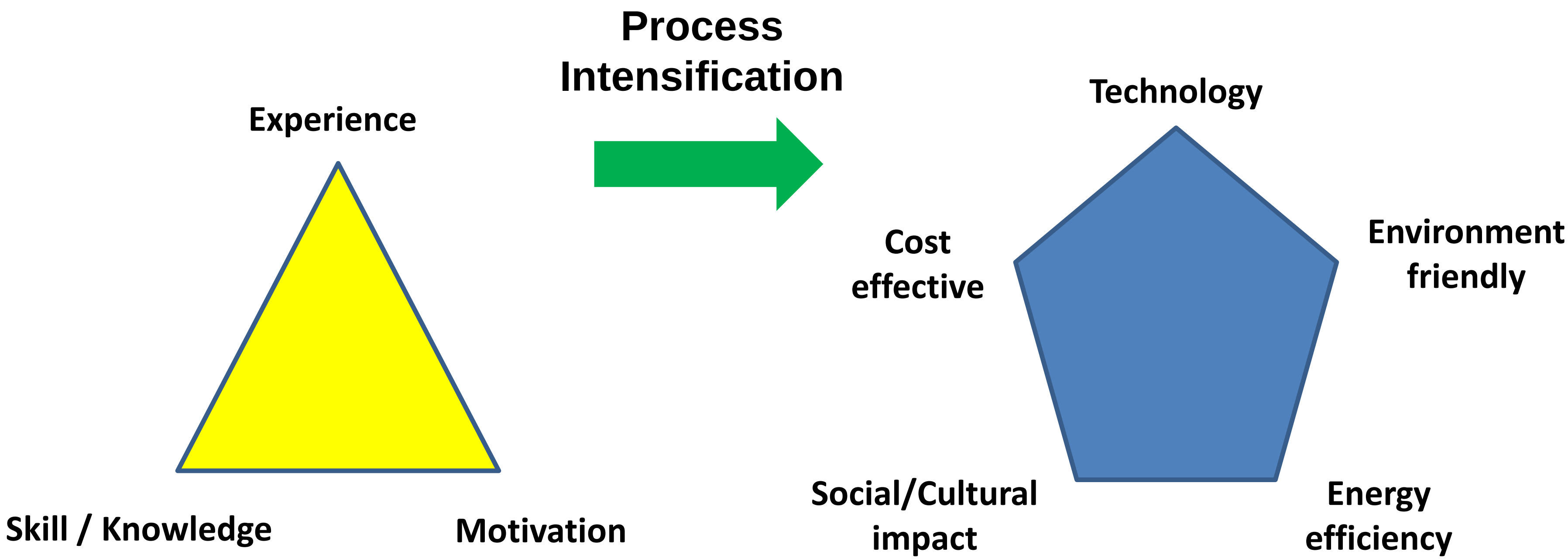
"micro-reactors will not provide the reliable plant the public is looking for"

Robbert De Graff
Safety Expert
Akzo Nobel Safety Labs

- ❑ Production vs storage
- ❑ Complexity in control and operation (reliability vs simplicity / cheap)
- ❑ Opens the way for more hazardous chemicals
- ❑ Replacing high-tech equipment is very expensive

It's a problem of a society that is focused on the lowest price and the cheapest product. For chemicals manufacturers, this means that the chemical cost price will determine which technology will be used, and as a result will surely determine the pace at which the technology will be accepted.

Science v Engineering



Largely individual based

Largely Society based

It is not about an engineering solution to producing chemicals efficiently, It is about producing chemicals efficiently, in large quantities, as safely as possible.

A PEEP INTO HISTORY

History of PI

SULPHURIC ACID

- LEAD CHAMBER PROCESS: 1749: John Roebuck (Inventor)
- GLOVER TOWER (MASS TRANSFER COLUMN): 1859: John Glover (Chemist)
- CONTACT PROCESS: 1831 (Platinum / Vanadium oxide): British vinegar merchant Peregrine Phillips

History of PI (Soda Ash)

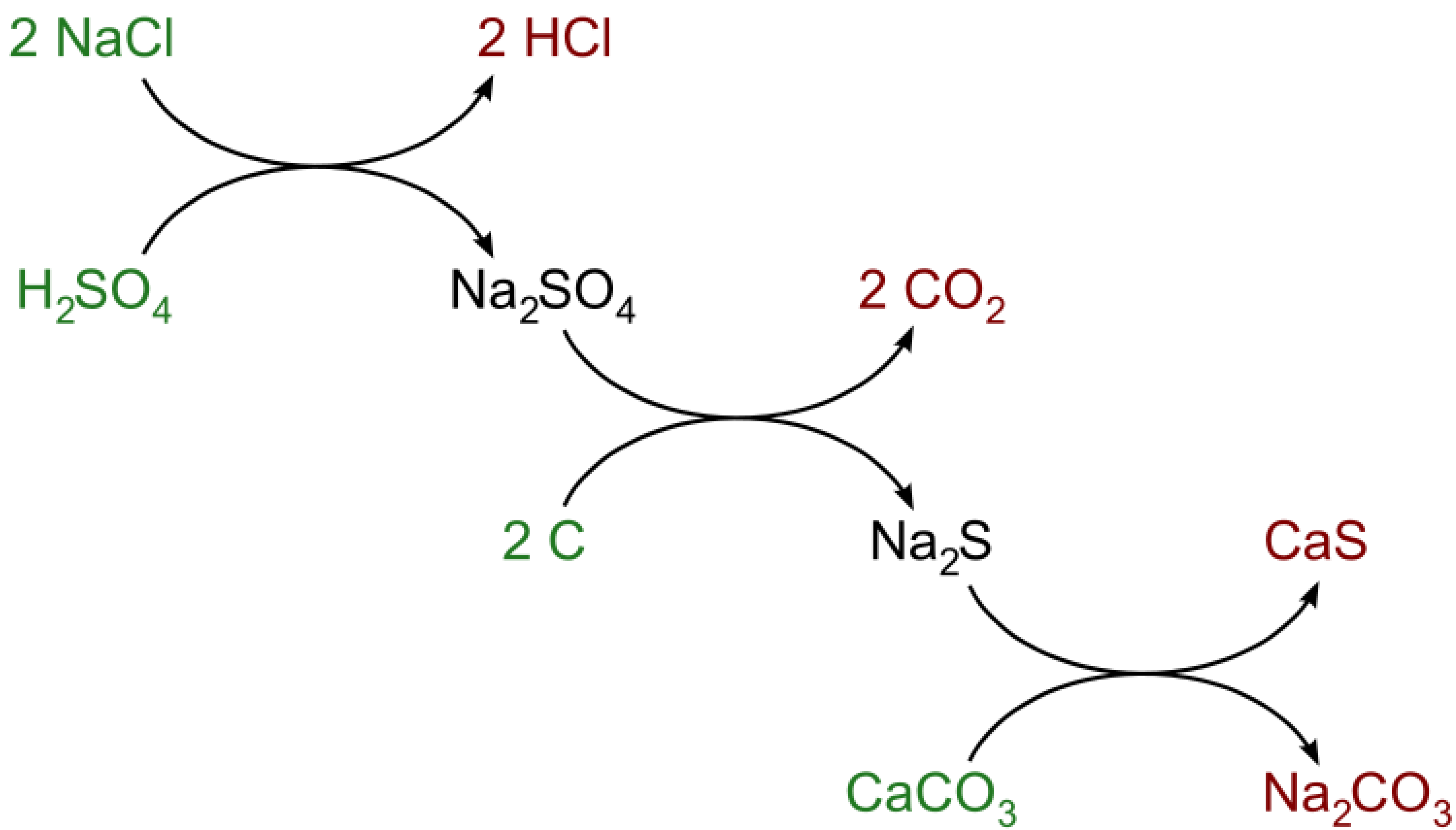
Nicolas Le Blanc Idea / Process (1789 / 1810): French Chemist and Surgeon

Carl Wilhelm Scheele $2\ NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2\ HCl$

$$Na_2SO_4 + 2\ C \rightarrow Na_2S + 2\ CO_2$$

$$Na_2S + CaCO_3 \rightarrow Na_2CO_3 + CaS$$

History of PI (Soda Ash)



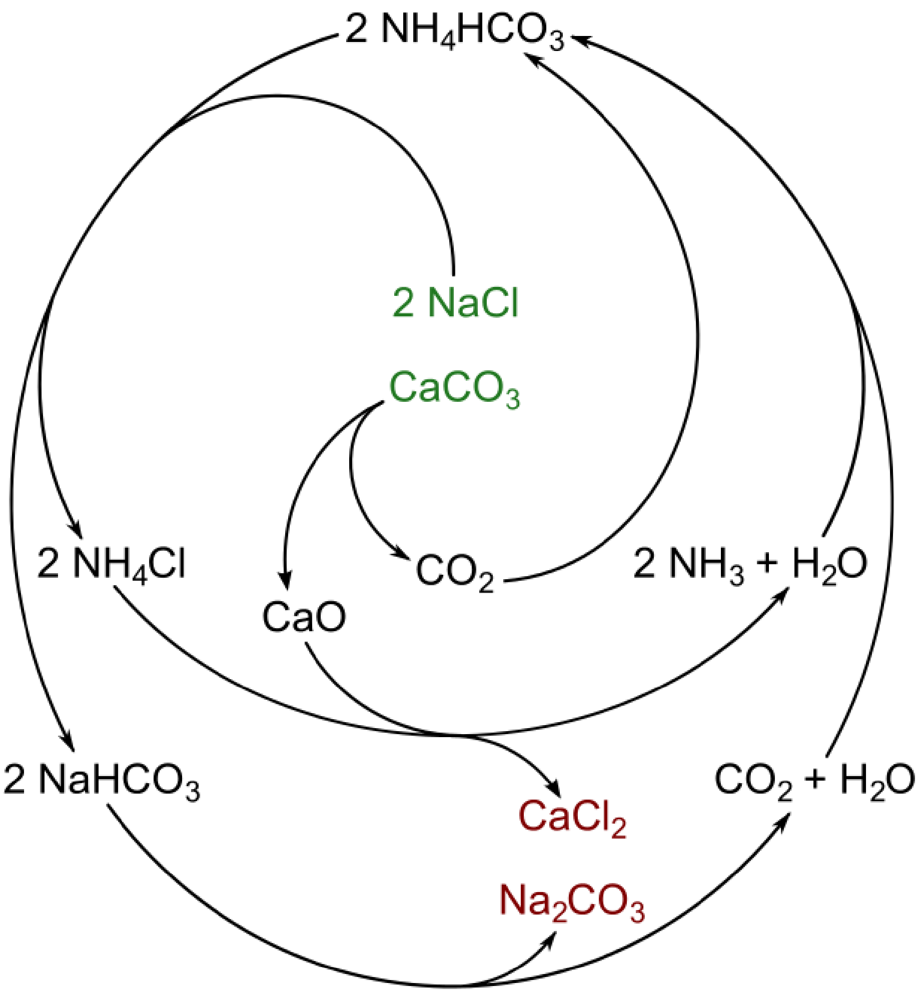
Petition (1839)

A petition against the Le Blanc Process in 1839 complained that "the gas from these manufactories is of such a deleterious nature as to blight everything within its influence, and is alike baneful to health and property. The herbage of the fields in their vicinity is scorched, the gardens neither yield fruit nor vegetables; many flourishing trees have lately become rotten naked sticks. Cattle and poultry droop and pine away. It tarnishes the furniture in our houses, and when we are exposed to it, which is of frequent occurrence, we are afflicted with coughs and pains in the head...all of which we attribute to the Alkali works."

History of PI (Soda Ash)

SOLVAY'S PROCESS

Belgian Chemist



CHEMICAL ENGINEERING WAS NOT BORN THEN

Not to forget Augustin John Fresnel (1711)!

Ammonia Manufacture

Natural gas $\Leftrightarrow$ Hydrogen

Desulphurization

$H_2 + RSH \rightarrow RH + H_2S(gas)$

$H_2S + ZnO \rightarrow ZnS + H_2O$

Reforming

$CH_4 + H_2O \rightarrow CO + 3H_2$

Shift Conversion

$CO + H_2O \rightarrow CO_2 + H_2$

Ammonia manufacture

$3H_2 + N_2 \rightarrow 2NH_3$

T = 400 K P = 200 ATM, K = 10^{-5}

BOMB! Thanks Mr. Chatelier

FRITZ HABER (GERMAN)

Oh NO!

HENRI LOUIS LE CHATELIER (FRENCH)

What was different?

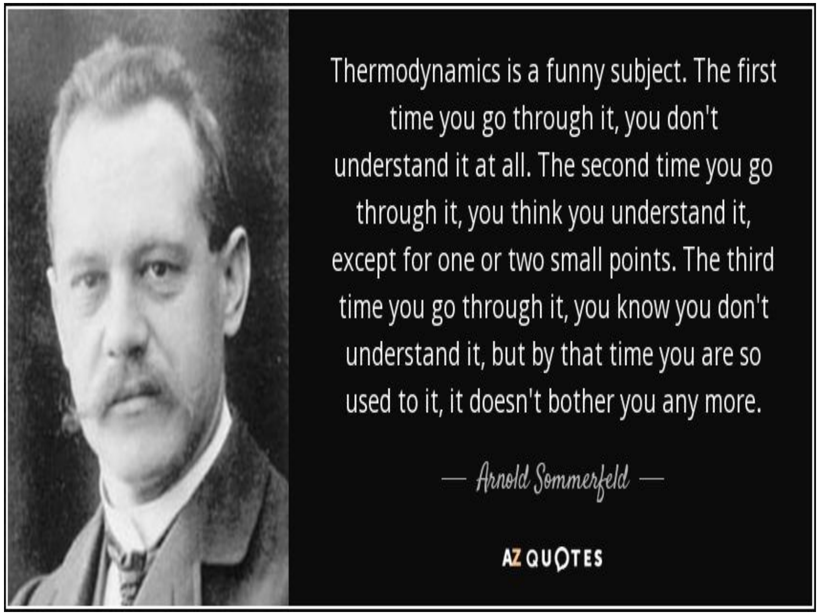
- Need Driven by some strange people with stranger backgrounds
- **Superbly backed by an understanding of thermodynamics and kinetics (from a process view point)**
- Segregated to Integrated approach
- Crude to Cleaner processes
- Very little hue and cry (Inter or Multi – disciplinary): There is trouble and it needs to be sorted….
- Movement was to translate Science to Engineering

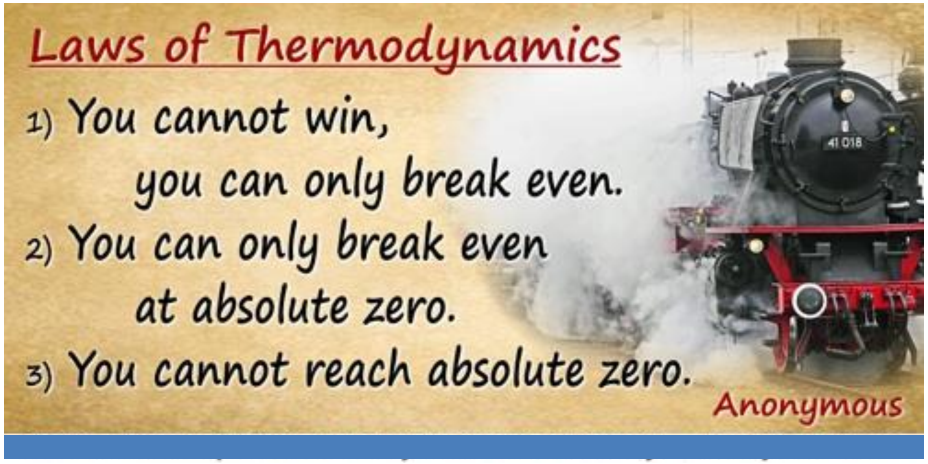
PI Challenges

- The issue of scale
- No definitive criteria on evaluating technology (Thermodynamics / Kinetics)
- Too much knowhow and skill available at one level, but <u>not connected nor is there an intent</u> to push and provide solutions (Specific expertise): Lack of global networks
- Technology Intensification dominating over Process Intensification
- New Technologies introduced showing existing ones as having weakness (improper evaluation of technologies)
- Repetitive work moving in parallel rather than moving forward. Adaptation level not to the desired mark
- Lack of knowhow on technology development in this area across the globe

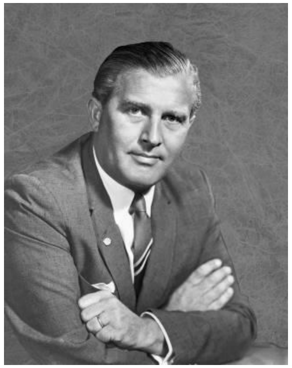
Unknowingly are we moving against History? The gap between seeking to know and seeking to do increasing…

Thermodynamics & Kinetics





Science has found out that nothing can disappear without a trace. Nature does not know extinction. All it knows is transformation



Wernher Von Braun

CO_2 conundrum (Issue of scale)

E&E NEWS

ENVIRONMENT

Global CO2 Emissions Rise after Paris Climate Agreement Signed

Emissions climbed in Asia and Europe, but declined in the U.S.

By Benjamin Storrow, E&E News on March 24, 2018

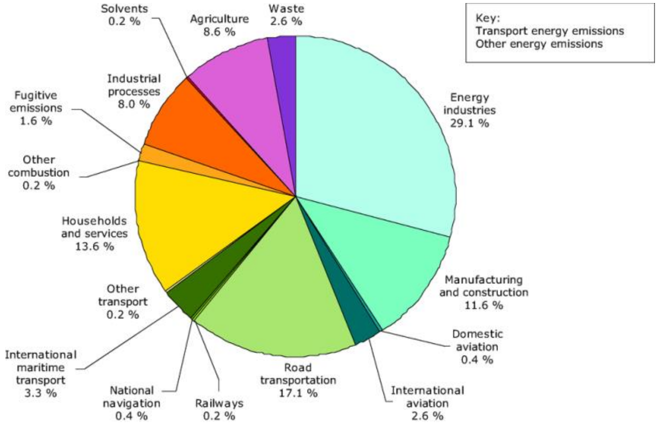
Energy-related emissions climbed 1.4 percent to 32.5 gigatons in 2017, the International Energy Agency reported yesterday in its annual survey of global carbon levels. The increase is the equivalent of adding 170 million cars to the road, the agency said.

The Climeworks carbon sucking plant in Switzerland. CLIMEWORKS

In Switzerland, a giant new machine is sucking carbon directly from the air

By Christa Marshall, E&E News | Jun. 1, 2017 , 10:30 AM

Is this an Isolated problem?



Consuming 11.5 billion sandwiches annually in the UK generates, on average, 9.5 million tonnes of CO_2 eq., equivalent to the annual use of 8.6 million cars.'

72% of the CO_2 molecule is Oxygen

Scale of emission vs. capture skewed

Fossil fuels the culprit!!

Energy Conundrum (Its forms)

- Kinetic Energy
- Mechanical Energy
- Potential Energy
- Nuclear energy
- Surface Energy
- Free Energy
- Enthalpy
- Heat
- Work
- Bond energy
- Internal Energy
- Helmholtz energy

DAILY USE VS. SCIENTIFIC USE

- **Multiple forms (a major headache) used as per convenience**

Other issues

"I don't know what energy is but if you have plenty of time I can teach you how to calculate it"

- ❑ **Conservation vs. balance**
- ❑ **Quantity vs. Quality**
- ❑ **Equilibrium vs. rate**

WITH ALL THIS CONFUSION WHY IS ENERGY IMPORTANT?

Importance of Energy

Energy by itself in quantum is not a concern, as it is conserved

The unused energy should a concern

Wasted potential (Anergy) should be a worry

Exergy should be the emphasis

Energy
- Right Amount

Energy
- Right Place

Energy
- Right Rate

Fortunately better placed in terms of technologies!!

Unmixed Combustion and Applications (Short / Medium Term)

1 project completed, 1 in progress on Unmixed Reforming (ICT)

OSRM development (synthesis, thermodynamics and kinetics)

UMC Group

1. Prof. Srinivas Krishnaswamy
2. Prof. Sutapa Roy Ramanan
3. Dr. Amol Deshpande

Reactor Development (CFD study based / pilot level)

Industry Connect in the context of applications (Thermax, David Reay and Associates)

PI: Materials Engineering

Dr. Sharad Sontakke

Research Interests: Materials Engineering, Water treatment, Waste to value added materials, Solar cells

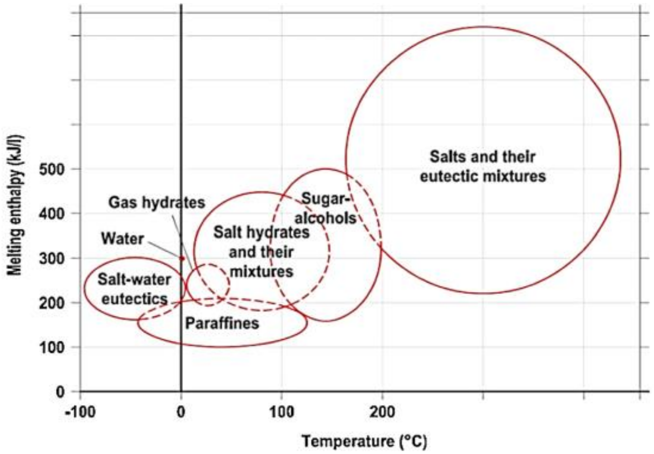


Fig. 19. Storage tank implemented in a real solar cooling installation at the University of Sevilla (Spain)

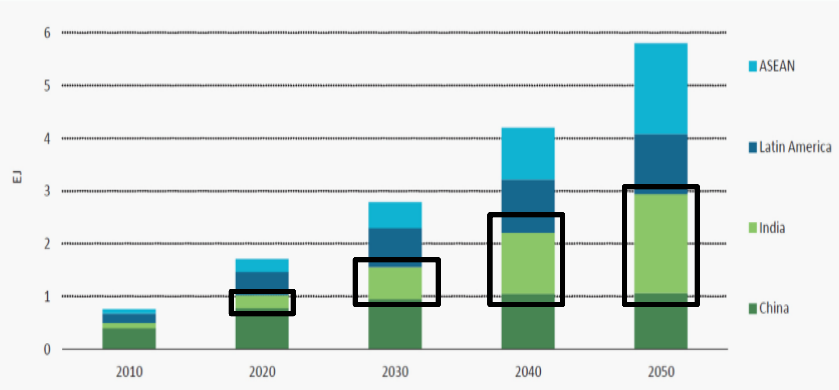


Fig. 2. Predicted evolution of cooling demand (Exa-joule "EJ") in four different regions [10].

Limitations:
Yet far from the commercialization due to region specific applications

'Way towards intensification'
Development of a methodology based on metrological data and temperature cycles for different PCM in order to optimize the best conditions

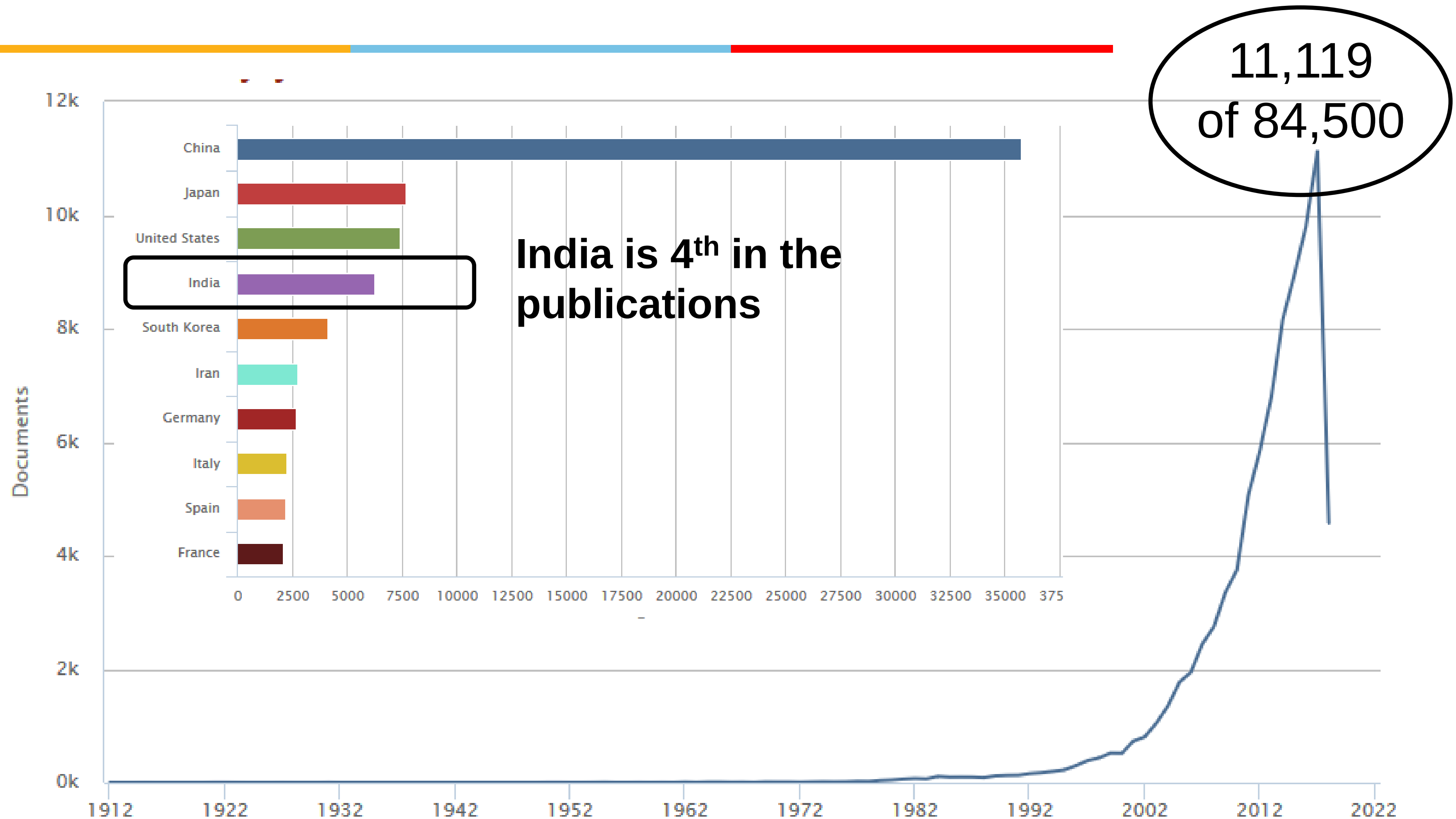
Water Treatment

- Since 1800's, but then are things getting better in terms of solutions?
- Selective on feed and product water quality
- Technology intensification the focus than Process Intensification
- Most technologies based on contaminating water further
- No detailed evaluation of Technologies
- Obsolete protocols with restricted understanding of new ones

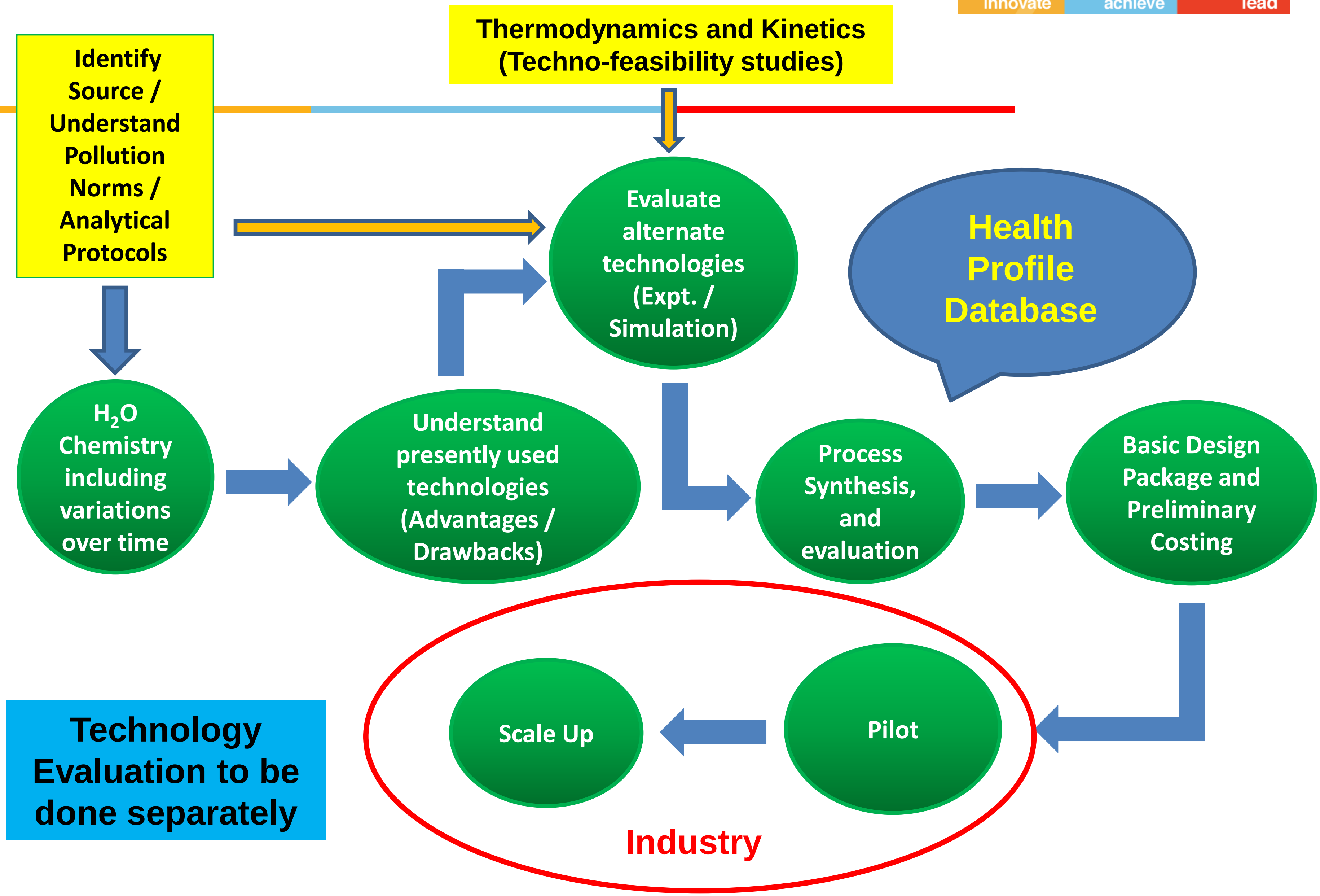
Talk of technologies and you will find it in this area

Publications on “Photocatalysis”

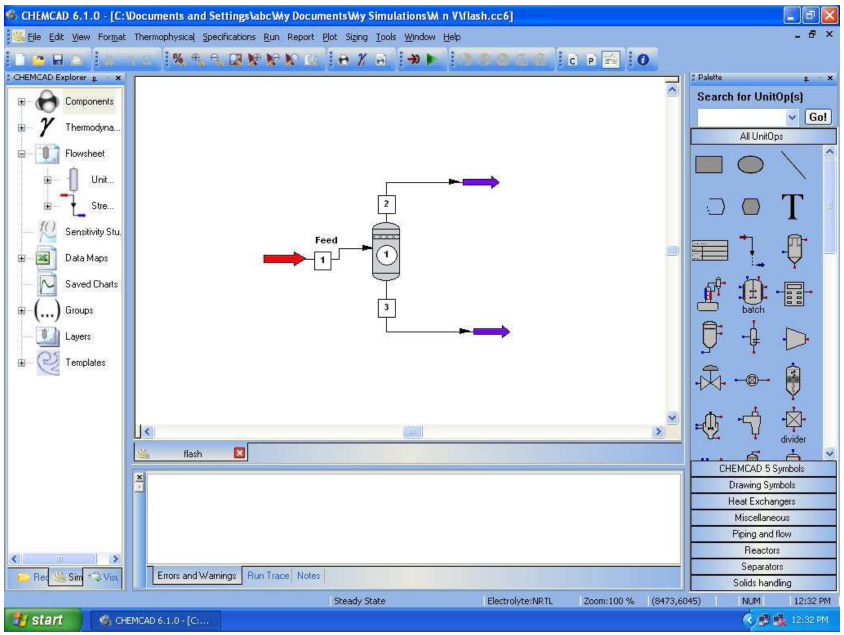
innovate achieve lead



Source: ‘Scopus’, accessed on 19th April, 2018


Thermodynamics and Kinetics (Techno-feasibility studies)
Identify Source / Understand Pollution Norms / Analytical Protocols
Evaluate alternate technologies (Expt. / Simulation)
Health Profile Database
H_2O Chemistry including variations over time
Understand presently used technologies (Advantages / Drawbacks)
Process Synthesis, and evaluation
Basic Design Package and Preliminary Costing
Technology Evaluation to be done separately
Scale Up
Pilot
Industry

Process Condensate Treatment in Ammonia fertilizer plants



Stream Name	Feed
Temperature / °C	125
Pressure / MPa (g)	2.6
Vapour mass fraction	0
Total mass flowrate / kg/hr	40000

Element/Compound	Typical Range (ppm)
Bicarbonate	1600 – 2600
Ammonia	2000 – 3000
Methanol	120 – 300
Chloride	10 – 70
Nitrate	0 – 10
Nitrite	0 – 10
Calcium	0 – 15
Iron	0 – 1

Water	39822
Methanol	24.68
Ammonia	0.20
Carbon dioxide	14.77
Ammonium bicarbonate	86.18
Ammonium chloride	36.98
Ammonium nitrate	4.99

Process Condensate Treatment in Ammonia fertilizer plants: Thermodynamic validation

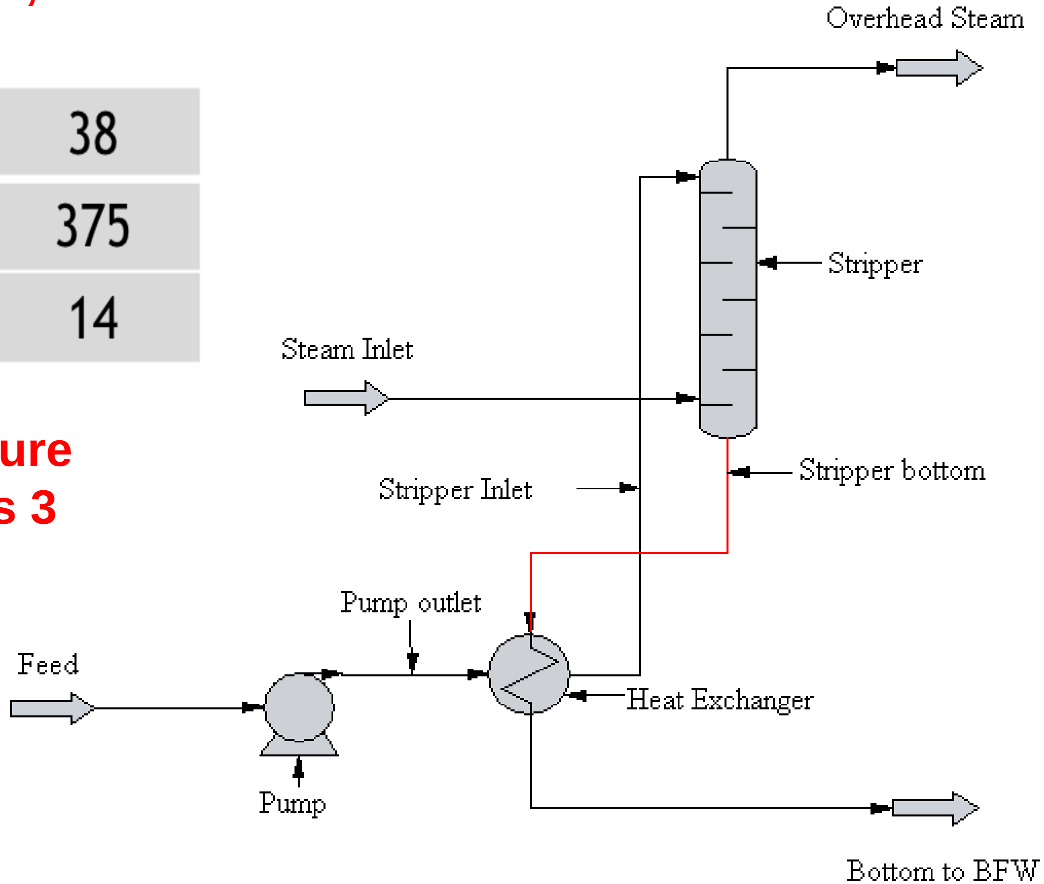
METHANOL							
Date	Input	Output from plant data	Output from Simulation				
			e-NRTL	NRTL	T K Wilson	HRNM	Wilson
21-Feb	261.80	271.00	248.51	248.28	256.32	256.32	248.18
22-Feb	275.00	276.40	261.07	260.69	269.22	269.22	260.62
11-Jul	617.00	585.00	585.88	585.17	604.18	604.20	585.14
12-Jul	512.00	495.00	486.11	485.48	501.32	501.31	485.33
13-Jul	327.00	312.00	310.98	310.56	320.37	320.38	310.60
14-Jul	583.00	563.00	553.38	552.71	570.82	570.81	552.56
17-Jul	312.00	302.00	296.97	296.59	305.80	305.81	296.61
AMMONIA							
Date	Input	Output from plant data	Output from Simulation				
			e-NRTL	NRTL	T K Wilson	HRNM	Wilson
21-Feb	573.00	590.00	578.40	577.59	577.59	577.59	577.61
22-Feb	729.00	758.00	735.90	734.91	734.88	734.89	734.91
11-Jul	582.00	610.00	587.44	586.65	586.60	586.59	586.63
12-Jul	638.00	654.00	644.00	643.13	643.08	643.09	643.14
13-Jul	602.00	609.00	607.37	606.43	606.38	606.37	606.39
14-Jul	599.00	604.00	604.66	603.84	603.79	603.79	603.85
17-Jul	559.00	582.00	563.46	561.76	561.71	561.71	561.74
CARBON DI-OXIDE							
Date	Input	Output from plant data	Output from Simulation				
			e-NRTL	NRTL	T K Wilson	HRNM	Wilson
21-Feb	1740.00	1405.00	1357.95	1345.61	1345.59	1345.59	1345.64
22-Feb	1855.00	1420.00	1447.51	1434.68	1434.62	1434.63	1434.68
11-Jul	1570.00	1270.00	1225.09	1214.11	1214.00	1213.99	1214.07
12-Jul	1683.00	1304.00	1313.27	1301.56	1301.46	1301.48	1301.58
13-Jul	1400.00	1089.00	1156.48	1148.37	1148.27	1148.26	1148.30
14-Jul	1711.00	1312.00	1335.23	1323.27	1323.15	1323.16	1323.28
17-Jul	1308.00	1108.00	1127.00	1120.76	1120.63	1120.61	1120.70

Process Condensate Treatment in Ammonia fertilizer plants: Evaluation of existing strippers

Tata Chemicals, Zuari Industries, RCF

PRESSURE / bar	3.5	11	38
TEMPERATURE / °C	130	200	375
STEAM (MT/HR)	7	9	14

Why this variation in temperature in the same equipment across 3 plants?



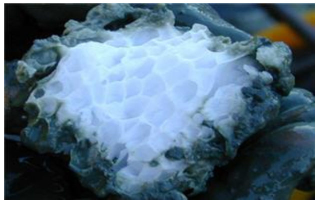
Evaluation of Unit operations and processes

Unit operation	Result	Accept / Reject
Ozonation (Experimental)	Good for methanol, not good for ammonia	Reject
Biological Treatment (Experimental)	Useful for ammonia and methanol. Kinetics an issue	Reject
Flash (Simulation)	Good for Carbon di-oxide	Accept
Membranes (Experimental)	Has potential, Issues of scale-up and handling of reject	Reject
Distillation (Simulation)	Good for methanol	Accept
Neutralization	Good for ammonia	Accept

Final Touches (Cost / Energy)

	Operating Pressure (bar)	Steam equivalent (MT/hr)	Energy Consumption (MJ/hr)	Annual Energy Cost in crore (INR)
Low Pressure Strippers	3	7.3	19,313	7.32
Moderate Pressure Strippers	8	9.2	24,174	9.16
High Pressure Strippers	37	16.9	44,453	16.85
Proposed Alternate Route for Process Condensate Treatment	-	7.72	20,369	7.72

Gas Hydrates



Potential for Desalination Demonstrated

Gas separation, Phase Change Material and hence refrigerant / coolant medium

Gas Hydrate

Prof. Srinivas Krishnaswamy

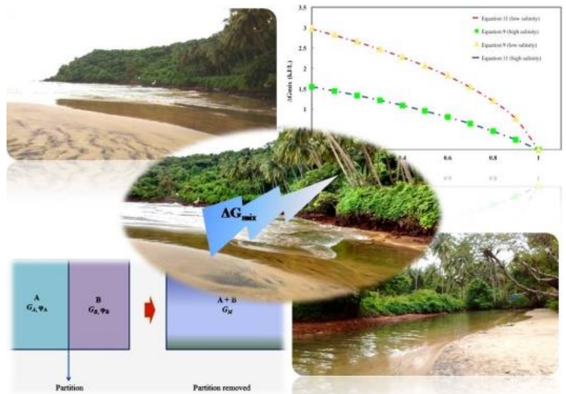
Slow kinetics, Understanding the effect of Surfactants

Industry Connect, Can we do this in a COBRA reactor?

PI: Water Energy Nexus (PRO)

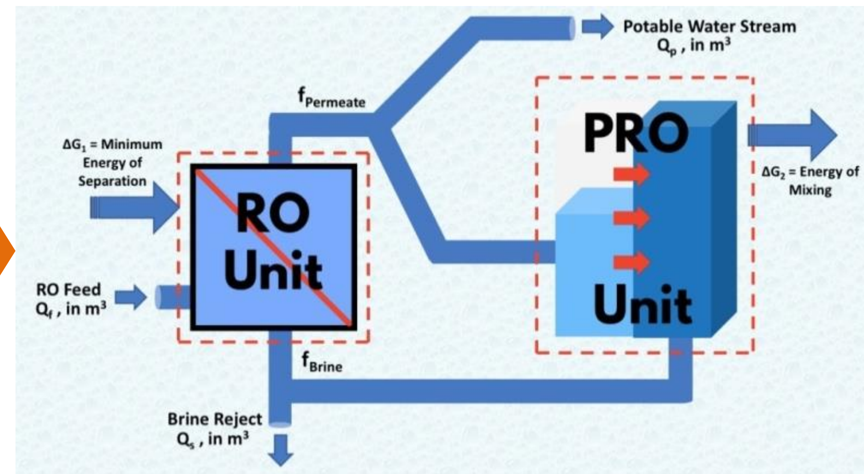
Dr. Anirban Roy

Research Interests: Thermodynamics, Membrane Separations, Biomedical Engineering



- Mixing of sea water and river water gives rise to energy equivalent of a 270 m waterfall
- 2009 Statkraft built the first PRO plant
- Mega-ton water system project built the second PRO plant in 2010 in Japan

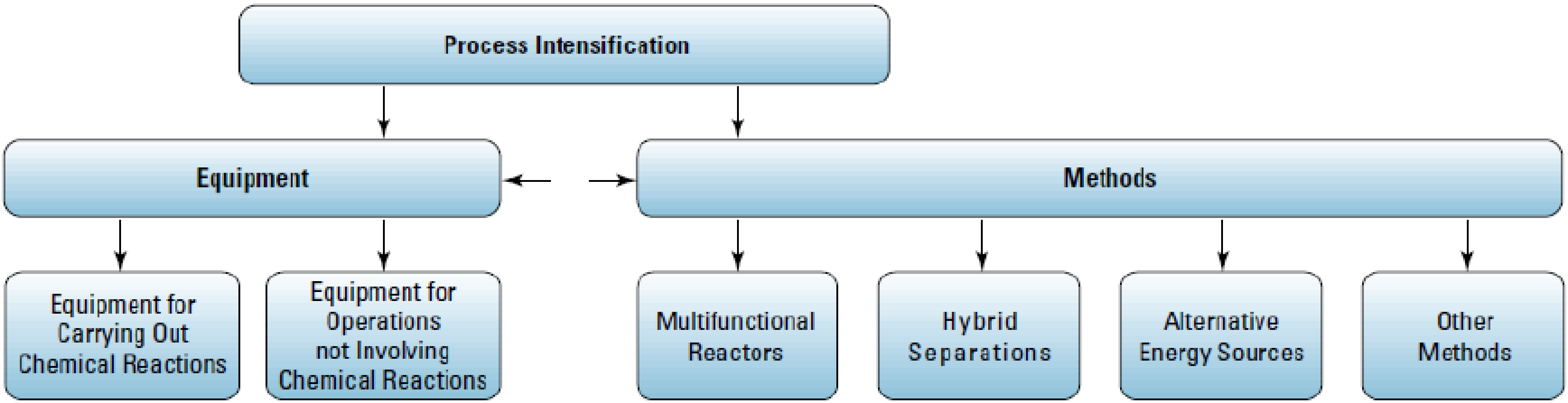
RO – PRO INTEGRATION



Process integration & intensification

- Synthesize membranes with high power densities
- Set up pilot plants using PRO technology
- Scale up analysis and related economic analysis
- Integrate RO-PRO and generate power from high salinity reject streams

Taxonomy of PI Technologies



Examples

Spinning Disk Reactor	Static Mixers	Reverse-Flow Reactors	Membrane Absorption	Centrifugal Fields	Supercritical Fluids
Static Mixer Reactor (SMR)	Compact Heat Exchangers	Reactive Distillation	Membrane Distillation	Ultrasound	Dynamic (Periodic) Reactor Operation
Static Mixing Catalysts (KATAPAKs)	Microchannel Heat Exchangers	Reactive Extraction	Adsorptive Distillation	Solar Energy	
Monolithic Reactors	Rotor/Stator Mixers	Reactive Crystallization		Microwaves	
Microreactors	Rotating Packed Beds	Chromatographic Reactors		Electric Fields	
Heat Exchange (HEX) Reactors	Centrifugal Adsorber	Periodic Separating Reactors		Plasma Technology	
Supersonic Gas/Liquid Reactor		Membrane Reactors			
Jet-Impingement Reactor		Reactive Extrusion			
Rotating Packed-Bed Reactor		Reactive Comminution			
		Fuel Cells			

Has Technology Intensification taken precedence over Process Intensification?

Approach to Process Intensification

- Understand the existing process clear (macro / micro) and the challenges involved
- Understand the limitations (thermodynamic / kinetic) & more so accept it. Do not push the limits at this stage
- Look for an alternative and its impact on the thermodynamics and kinetics
- Check the advances in this area (Do not repeat)
- Identify Challenges (preferably at application level)
- Frame solutions to address these challenges

Teaching vs. Research

Interdisciplinary and Multidisciplinary research still not connected, seeking more to know than do…

Success in PI

MY DEFINITION OF PI

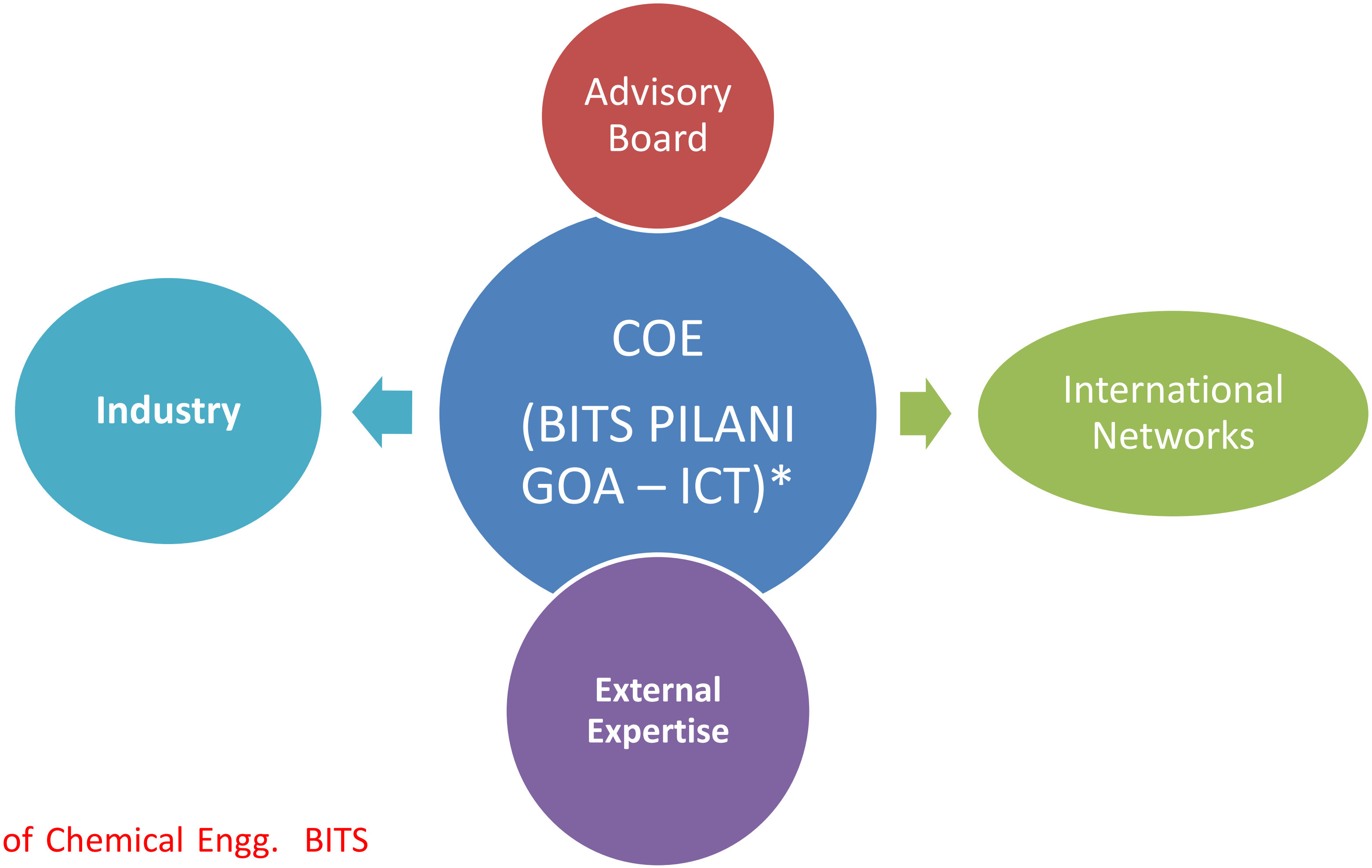
IT IS NOT JUST ABOUT KNOWING THINGS, IT IS ABOUT DOING THINGS IN TERMS OF PROCESS ENGINEERING & DEVELOPMENT

Centre of Excellence in PI

- Initiate the setting up of a **joint collaborative** Centre of Excellence in Process Intensification at BITS Pilani K K Birla Goa Campus in collaboration with Institute of Chemical Technology (ICT), Mumbai.

- In the long run, the Centre is expected to create a unique platform / network in the country for researchers in academia and practicing professionals in the Chemical Process Industry to work in conjunction and address challenges posed in **improving existing and developing new processes** from a practical, sustainable, cost effective, energy efficient, safe, and environment friendly viewpoint, thereby attempting to **bridge** the gap between know-why and know-how.

Structure of the Centre



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Acknowledgements

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गेल
GAIL

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THERMAX

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Department Of Fertilizers
Ministry of Chemicals and Fertilizers
Government of India


Thank You!