INNOVATIVE TECHNOLOGIES FOR INCREASED PROFITABILITY AND SUSTAINABLE MANUFACTURING IN CHEMICAL AND RELATED INDUSTRIES:

PROCESS INTENSIFICATION

Andrzej Stankiewicz
Steam Cracker - Cathedral of the Chemical Industries of 20th Century
12 EIA World Conventional Oil Production Scenarios

USGS Estimates of Ultimate Recovery

<table>
<thead>
<tr>
<th>Probability</th>
<th>Ultimate Recovery BBls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (95 %)</td>
<td>2,248</td>
</tr>
<tr>
<td>Mean (expected value)</td>
<td>3,003</td>
</tr>
<tr>
<td>High (5 %)</td>
<td>3,896</td>
</tr>
</tbody>
</table>

Peak Range 46 yrs or 91 yrs

2021 2067 2112

3 % Growth

900 Billion Bbls Moves Peak 10 Years From 2037 - 2047

2 % Growth

1 % Growth

Decline R/P = 10

0 % Growth

Note: U.S. volumes were added to the USGS foreign volumes to obtain world totals.

(J. Wood, G. Long, Energy Information Administration, 2000)
SOME FORECASTS:

- **WE WILL ESSENTIALLY USE UP ALL THE WORLD’S OIL RESOURCES BY 2050** (S. A. Nelson)

- **WE WILL ESSENTIALLY USE UP ALL THE WORLD’S GAS RESOURCES BY 2070** (P.-R. Baquis)

- **WE WILL ESSENTIALLY USE UP ALL THE WORLD’S COAL RESOURCES BY 2500** (S. A. Nelson)
Only 25% of what goes into the pipe comes out as goods and services

World Resource Institute (pathways.wri.com)
CEFIC (European Chemical Industry Council) – European Technology Platform for Sustainable Chemistry:

"...the only way to remain profitable under [...] high cost pressure conditions is to keep a high level of excellence in the area of process intensification".
Cost reduction via optimization of the primary business work processes

- sooner or later a critical limit will be reached
- competitors will follow
- the only way to go beyond that limit and gain significant long-term advantage over the competitors is via innovative technological development
THE HIGHEST TIME TO INNOVATE!

AD 1556

AD 2005
Process Intensification

Aims at **DRATIC INCREASE** in **EFFICIENCY** of chemical and biochemical manufacturing by development and implementation of **INNOVATIVE** equipment and processing methods.

= 

**USING MUCH LESS TO PRODUCE MUCH MORE**

LESS = investment, space, time, raw materials, energy, inventory etc. 
MUCH = tens to thousands percent!!!
Process Intensification – What does it offer?

- Energy
- Materials
- Risk and hazard
- Cost
- Waste
- Reducing nuisances (odour, noise, etc.)
Process Intensification: cost reduction

(source: DSM)
Room for improvement…

Risk in Industry

Amateur systems  Safe systems  Ultra-safe systems

Himalaya mountaineering  Medical risk (total)  Chartered flight

Chemical Process Industry  Road safety  Civil aviation

Railways (France)  Nuclear Industry

$10^2$  $10^3$  $10^4$  $10^5$  $10^6$  Fatal risk

(after: R. Amalberti)

PRODUCTIE PROCES AUTOMATISERING DAG
### Improved safety

**SMALLER is SAFER!**

<table>
<thead>
<tr>
<th>PLACE</th>
<th>DATE</th>
<th>CHEMICAL</th>
<th>ESTIMATED AMOUNT</th>
<th>CASUALTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oppau/Ludwigshafen</td>
<td>September 21, 1921</td>
<td>ammonium sulfate, ammonium nitrate</td>
<td>4,500 t exploded</td>
<td>ca. 550 + 50 dead, 1,500 injured</td>
</tr>
<tr>
<td>Flixborough</td>
<td>June 1, 1974</td>
<td>cyclohexane</td>
<td>400 ton inventory, 40 ton escaped</td>
<td>28 dead, 36 + 53 injured</td>
</tr>
<tr>
<td>Beek</td>
<td>November 7, 1975</td>
<td>(mainly) propylene</td>
<td>&gt; 10,000 m³ inventory, 5.5 ton escaped</td>
<td>14 dead, 104 + 3 injured</td>
</tr>
<tr>
<td>Seveso</td>
<td>July 10, 1976</td>
<td>2,4,5 trichlorophenol, dioxin</td>
<td>7 ton inventory, 3 ton escaped</td>
<td>no direct casualties, ca. 37,000 people exposed</td>
</tr>
<tr>
<td>San Juan, Mexico City</td>
<td>November 19, 1984</td>
<td>LPG</td>
<td>&gt; 10,000 m³ inventory</td>
<td>5 + ca. 500 dead, 2 + 7000 injured (mainly outside the plant)</td>
</tr>
<tr>
<td>Bhopal</td>
<td>December 3, 1984</td>
<td>methyl isocyanate</td>
<td>41 ton released</td>
<td>3,800 dead, 2,720 permanently disabled</td>
</tr>
<tr>
<td>Pasadena</td>
<td>October 23, 1989</td>
<td>ethylene, isobutane, hexene, hydrogen</td>
<td>33 ton escaped</td>
<td>23 dead, 130-300 injured</td>
</tr>
<tr>
<td>Toulouse</td>
<td>September 21, 2001</td>
<td>ammonium nitrate</td>
<td>200-300 ton</td>
<td>31 dead, 2442 injured</td>
</tr>
</tbody>
</table>
Science helps build a new India

Oxen working the fields ... the eternal river Ganges ... jeweled elephants on parade. Today these symbols of ancient India exist side by side with a new sight — modern industry. India has developed bold new plans to build its economy and bring the promise of a bright future to its more than 400,000,000 people. But India needs the technical knowledge of the Western world. For example, working with Indian engineers and technicians, Union Carbide recently made available its vast scientific resources to help build a major chemicals and plastics plant near Bombay. Throughout the free world, Union Carbide has been actively engaged in building plants for the manufacture of chemicals, plastics, carbons, gases, and metals. The people of Union Carbide welcome the opportunity to use their knowledge and skills in partnership with the citizens of so many great countries.
BHOPAL LESSON: using process-intensive continuous reactors, methyl isocyanate could have been generated and immediately converted to final products in a process that contained a total inventory of less than 10 kg of MIC! (source: AIChE)
PI Elements

Process Intensification

EQUIPMENT

- REACTORS
  - spinning disk reactor
  - static mixer reactor
  - monolithic reactor
  - microreactor

- EQUIPMENT FOR NON-REACTIVE OPERATIONS
  - static mixer
  - compact heat exchanger
  - rotating packed bed
  - centrifugal adsorber

- MULTIFUNCTIONAL REACTORS
  - heat-integrated reactors
  - reactive separations
  - reactive comminution
  - reactive extrusion
  - fuel cells

- HYBRID SEPARATIONS
  - membrane absorption
  - membrane distillation
  - adsorptive distillation

- ALTERNATIVE ENERGY SOURCES
  - centrifugal fields
  - ultrasounds
  - solar energy
  - microwaves
  - electric fields
  - plasma technology

- OTHER METHODS
  - supercritical fluids
  - dynamic (periodic) reactor operation

Examples:

- PI Elements
GREEN  effects of PI: less inventory, more selectivity & control

Heat transfer coefficients exceeding 20,000 W/m²K (FZ Karlsruhe)

Reaction time reduced by 99.9%, inventory by 99%! (GlaxoSmithKline)

Conversion increased from 25% to 85%, selectivity from 83% to 95%! (BASF)

Reaction time reduced from 18 hrs to 15 mins! (Hickson & Welch)

HEX Reactor by BHR Group Ltd.

PRODUCTIE PROCES AUTOMATISERING DAG
GREEN effects of PI: less inventory, less complexity, less energy
1. Reactor
2. Stripper
3. Condenser
4. Scrubber
5. Pool condenser
6. Pool reactor

simple lay-out  *** reduced piping *** less structural steel
PI examples - DSM MELAMINE TECHNOLOGY

Utilities (per metric ton of Melamine):
- Natural gas: 7 GJ (reactor) (- 30 %)
- Steam: < 1 ton (- 85 %)
- Electricity: < 0.4 MWh (- 0 %)
- Cooling water: < 400 ton (- 40 %)

Major energy savings
Major plant size reduction
Erfolgreicher Einsatz eines Mikroreaktors in der chemischen Produktion bei DSM Fine Chemicals

- Durchsatz: 1 - 2 Tonnen pro Stunde flüssige Chemikalien
- Wärmeabfuhrkapazität: mehrere 100 kW
- 10-wöchige Produktionskampagne im Frühjahr 2005
- Über 300 to Produkt erzeugt
- Erhöhung der Ausbeute und Absenkung von Rohstoffeinsatz, Abfallströmen und Energieverbrauch im Vergleich zum Rührkessel

Institut für Mikroverfahrenstechnik
The chemical plant of tomorrow

- compact
- integrated
- utilizing alternative sources and form of energy
• Process Intensification presents the key innovative element of sustainable development in chemical and related industries, resulting in combination of substantial increase of cost-competitiveness with improved safety and environment-friendly processing
Future Chances?

Process Intensification - a road to Process Robotization in Chemical Plants?