

# Structured Multiscale Design for Sustainable Process Intensification

Methods and Tools for the Future of the Chemical Process Industries

## OUTLINE

TALK

- CONTEXT :** sustainability and industrial production
- OPPORTUNITY :** microstructured process engineering
- APPROACH :** multiscale design for sustainable  
process intensification
- PERSPECTIVES :** the challenges for the next decade



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**Innovative PRODUCTION :**  
**a vital role for INDUSTRY in the quest**  
**for sustainable development**

The **AMBITION** of eco-efficiency : **CLOSING LOOPS** in the life cycle

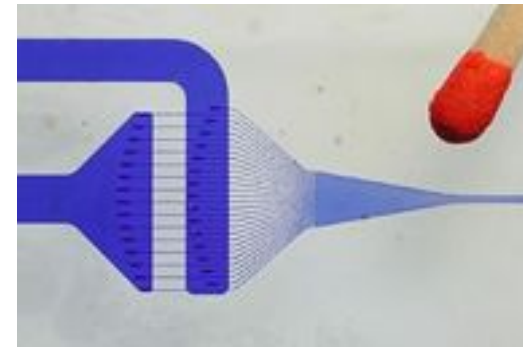




# Microstructured component technology : an opportunity for the chemical process industries ?

**Intensified  
Process  
Equipment**

- micromixers
- thin-film contactors
- microreactors
- compact exchangers



(Source : IMM)



(Source : FZK)

**Essential  
features**



**Controlled topology**

( on a sub-millimeter scale :  
relevant for transfer/mixing )

**Diverse materials**

( metals, alloys, glass, ceramics,  
polymers : not only silicon ! )



(Source : mikrogas)

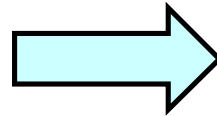


**Initial success of microprocess engineering :**  
**laboratory application (not process !)**

## **LABORATORY application = chemical INFORMATION**

(« smaller is generally better » : smaller sample sizes and faster response)

Analysis, Screening  
Combinatorial chemistry  
Genomics, Proteomics

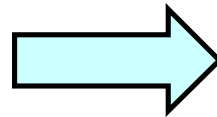


- Wide-spread interest
- Strong markets
- Industrial application

## **PRODUCTION application = chemical TRANSFORMATION**

(« smaller is only better if you are clever ! » : process / business innovation)

Intensification,  
Miniaturization



- Limited interest (niche)
- Slow development (risk)

**What is needed to promote production application ?**

**Appropriate process (and business) development tools !**



**The strategic goal of Process Intensification :  
innovative methods and devices for sustainability**

## **Process Intensification : doing more with less !**

### **DEFINITION (\*)**

**Development of innovative methods and devices which, in comparison to those existing today, offer the perspective of a DRAMATIC improvement in the quality of production and/or a significant reduction in size, energy consumption and/or production of waste,**

**resulting ultimately in technologies that are less expensive and more « sustainable »**

(\*) Definition adapted from A. STANKIEWICZ and J. A. MOULIJN, *Chemical Engineering Progress*, January 2000, pp. 22–34.



## Process intensification via Microprocess Engineering : the concept of **Structured Multiscale Design**

### A new approach to chemical process design !

#### **STRUCTURED MULTISCALE DESIGN**

**Principle :** **construction of large-scale production systems with small-scale inner-structuring at specifically targeted points (= locally structured elements)**

**Claim :** an opportunity for a **RADICAL increase in process performance** and a **MAJOR contribution to process intensification** for the chemical industries

**Approach :** « put chemistry in the center ! »

rather than adapting chemistry to equipment limitations, **adapt the equipment to IMPOSE the local operating conditions** required by the desired chemistry !

**Need :** a rational engineering **design methodology** to put **Structured Multiscale Design** into practice !



**The IMPULSE Project :**  
a European response  
to a global challenge



6th European Framework Programme for  
Research and Technological Development

**I**ntegrated  
**M**ultiscale  
**P**rocess  
**U**nits with  
**L**ocally  
**S**tructured  
**E**lements

**Project goal :**

Effective **targeted integration of innovative process equipment** (such as microreactors, compact heat exchangers, thin-film devices and other micro and / or meso-structured components) to attain radical performance enhancement for whole process

**Industrial leaders :** GSK, Evonik (\*), P&G, Siemens

**Consortium :** 20 partners from 8 European countries

**Project resources :** 17 M€ over 4 years  
(of which 10,5 M€ from the European Commission)



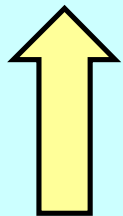
(\*) Degussa



## Structured Multiscale Design METHODOLOGY : can process intensification be made sustainable ??

### An urgent need for an integrated approach !

**SUSTAINABLE  
PROCESS  
INTENSIFICATION**



**STRUCTURED  
MULTISCALE  
DESIGN**

**Fact :** microstructuring reduces inner dimensions for contact with process fluids, thereby improving transport processes (e. g., heat and mass transfer, mixing, ...). Increased transfer rates result in an **increase in process productivity**

**Issue :** an increase in process **productivity is not enough !** the increase must also be « **SUSTAINABLE** » !

### Important Question : ENERGY !

Is a productivity increase really possible without a substantial **increase in energy dissipation ??**

**If not, we have a (big !) problem with sustainability !!**





**Fundamental feature of structured multiscale design (\*) :**  
**flow division : the additional degree of freedom we need !**

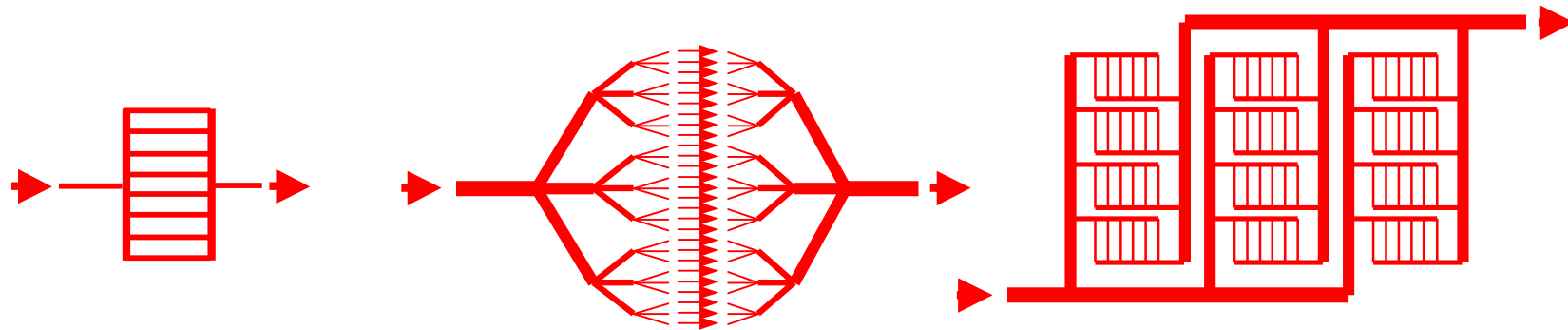
**Problem : reduction in characteristic heat transfer time without modification of the geometrical structure of the reactor will ALWAYS require a significant INCREASE in dissipated mechanical energy**

$$\frac{\varepsilon_2}{\varepsilon_1} \sim \left( \frac{t_1}{t_2} \right)^{3 \text{ to } 9}$$

3 to 9 : exponent depends on flow regime

**Solution :**

**targeted flow division and multiscale design can allow BOTH heat transfer time AND energy dissipation to be reduced (but you have to choose your parameters correctly !)**

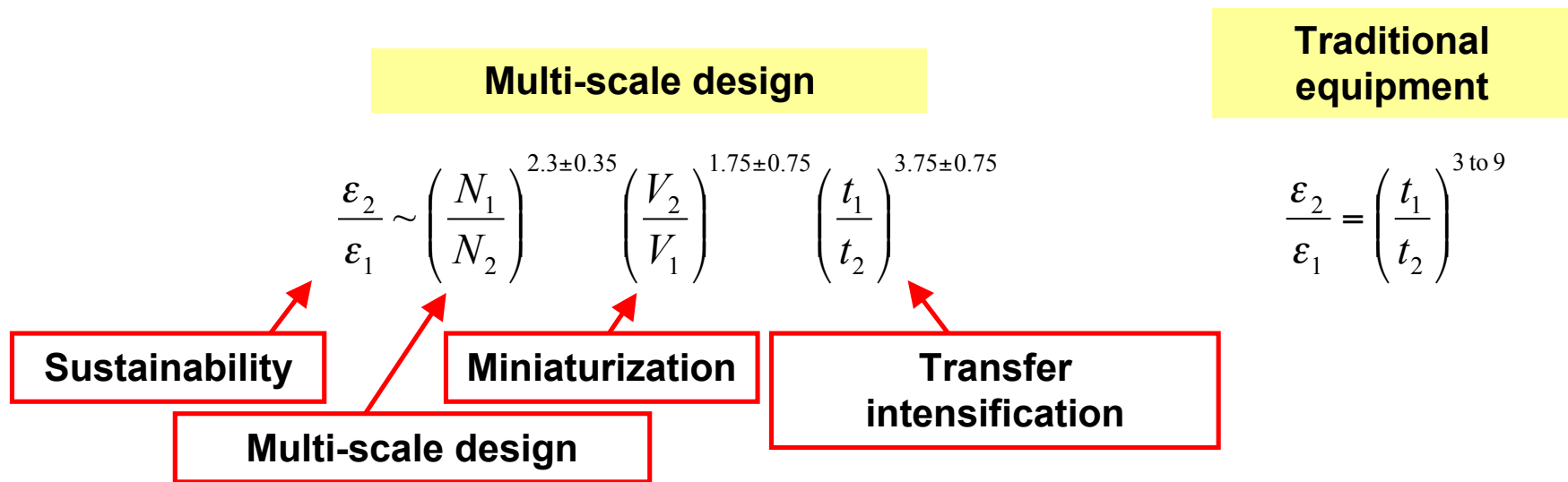




**Process intensification for rapid exothermic reaction :  
multiscale design equation for flow division (\*)**

**IMPULSE structured multiscale design methodology :**  
targeted geometrical (micro)structuring is key !

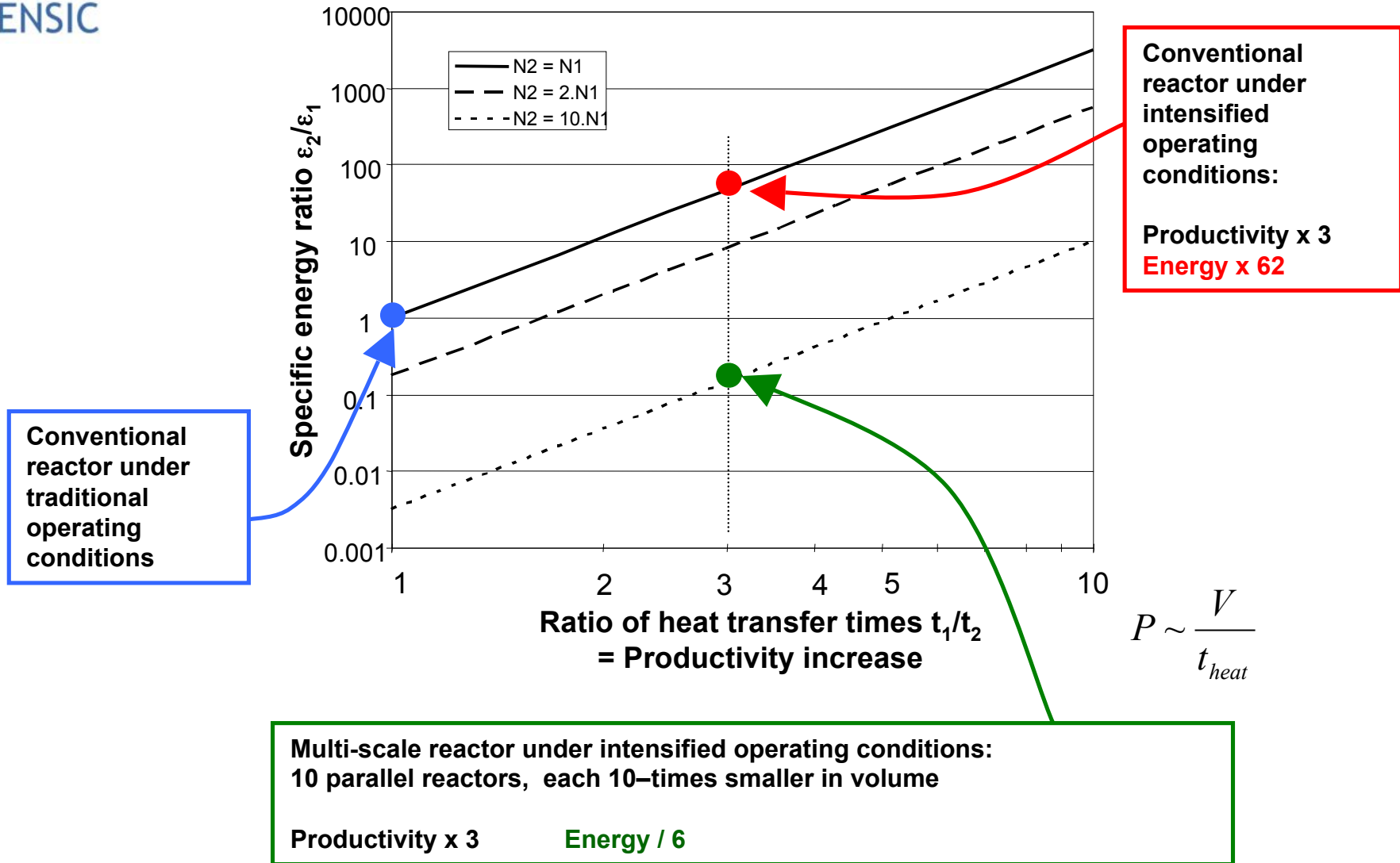
Reduced energy dissipation  $\varepsilon$  due to **flow division** into  $N$  parallel « channels »  
can compensate increased energy dissipation due to minaturization (reduced  $V$ )  
 and intensification (reduced  $t$ ).



(\*) M. Matlosz, L. Falk, J.-M. Commenge, *Handbook of Micro Process Engineering*, Vol. 3, 2008



## Process intensification for rapid exothermic reaction : illustration of potential performance enhancement (\*)



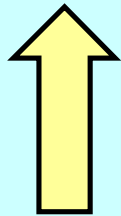
(\*) L. Falk, J.-M. Commenge : LSGC Laboratory, Nancy (to be published)



A sustainable chemical process industry :  
**can process innovation be made profitable ??**

**An urgent need for new business ideas !**

**SUSTAINABLE  
CHEMICAL  
PROCESS  
INDUSTRIES**



**STRUCTURED  
MULTISCALE  
DESIGN  
+  
NEW BUSINESS  
MODELS**

Fact : **structured multiscale design** can (potentially) **increase process productivity** while maintaining (or even reducing !) energy dissipation

Conclusion : microprocess engineering can (potentially) provide substantial **enhancement of performance**

Issue : an increase in process **performance is not enough !** the increase must also be « PROFITABLE » !

**Important Question : COST !**

Is performance enhancement really possible without a substantial **increase in CAPITAL INVESTMENT ??**

If not, we have a (big !) problem with sustainability !!



## The IMPULSE Vision : a **NEW GENERATION** of chemical plants

Rethink the **ROLE of PRODUCTION** in the chemical industry

**New  
technologies**

- **flexible** process devices
- **locally targeted** control
- « **programmable** » reactors
- **portable** process equipment

**New business  
models**

- **on site, on demand** manufacture
- **distributed, delocalized** production
- **variable, modular** throughput
- **mass customization** of product properties  
(down to the **NANO scale** !)



## The IMPULSE approach and project goals : Objective-driven fundamental research

### Project Goals



The key IMPULSE  
« Deliverables »

- ⇒ **Design methods and tools = HOW**
- ⇒ **Decision-making criteria = WHEN**

### Conditions for Project Success

The key DEMANDS  
on the IMPULSE  
« Deliverables »

Methods, tools and criteria must be :

**relevant,  
reliable,  
accessible**      AND      **« teachable » !!**



## Beyond IMPULSE : Future challenges for industrial development

### 1 Major Objective

**Overcoming barriers to wide-spread, routine implementation** of intensified, multiscale technologies over a broad range of application areas and production scales

### 2 Key Challenges

#### – breaking economies of scale

- robust, low-cost microcomponents
- a market (and standards) for equipment manufacturers
- new production paradigms for MUCH lower capital investment

#### – intensifying **PRODUCT** engineering

- targeted production of end-use properties through local process control
- methods for accelerated scale-up from bench-top to production



**SUMMARY :**  
**Why Structured Multiscale Design ? Why NOW ?**  
**And what NEXT ?**

**CONTEXT**

The challenges and demands of **sustainable development** require **MAJOR INNOVATION** in the methods and tools of **INDUSTRIAL PRODUCTION**

**OPPORTUNITY**

Intensified **microstructured process components** and devices of proven performance currently **available and capable of enhancing PROCESS PERFORMANCE** in the chemical industries

**APPROACH**

**Structured multiscale design methodology** (and corresponding **tools**) for techno-economic evaluation, decision-making, process development and scale-up

**PERSPECTIVES**

**RADICAL reduction in COST** for microstructured components and devices, development of **new business models** and strategies, reation of a new discipline : **intensified PRODUCT engineering !**