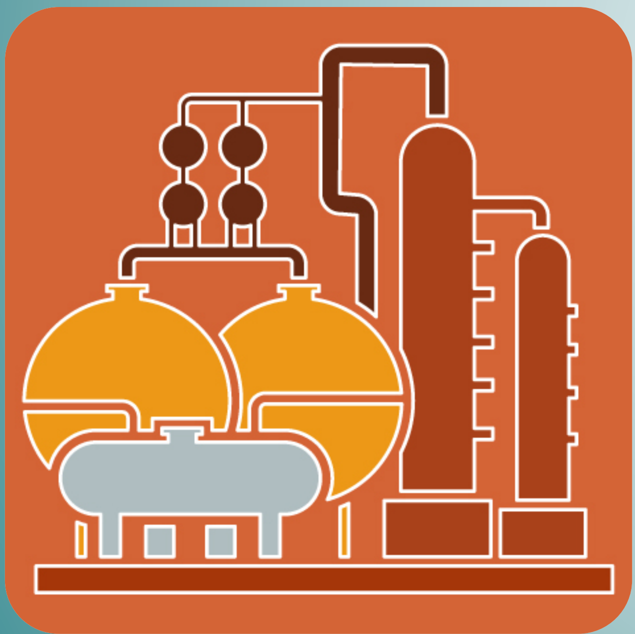
Chemical Process Design / Diseño de Procesos Químicos

Topic 1. Introduction to Chemical Process System Design



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GER Green Engineering and Resources Research Group

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1.- General information: The subject

Chemical Engineering Degree UC: Third Year. First Semester. Compulsory Module Industrial Chemistry. 6 ECTS.

Course meeting times: Two sessions/week. Classroom 07.
Tu: 09:30-11:30; Group 1 W: 08.30-10:30; Group 2 W: 15:30-17:30

Instructor: J.R. Viguri, ETSIIT, Office 313.
E. Cifrian, ETSIIT, Office 419.

GER Green Engineering and Resources Research Group
www.geruc.es

2.- Context: Process System Design

Discuss the following questions in groups of three. Write the ideas down on a sheet of paper. Summary in Group A and B

Chemical Engineering (Group A- Prof. 1)

- **Definition of Chemical Engineering: key words**
- **Work of Chemical Engineers**

Chemical Industry (Group B- Prof. 2)

- **Why is it important?**
- **Specific characteristics of the chemical industry**

Chemical Engineering (Group A- Prof. 1) **??** **Chemical Industry (Group B- Prof. 2)**

What are the characteristics of the chemical industry that determine design features of chemical processes??

See Slides 8 to 16 !!!!!!

2.- Context: Chemical Engineering

What is Chemical Engineering?

In 1924 the Institution of Chemical Engineers (IChemE) adopted: “A chemical engineer is a professional man experienced in the design, construction and operation of plant and works in which matter undergoes a change of state and composition”.

In 1983 the American Institute of Chemical Engineers (AIChE) defined that: “Chemical engineering is the profession in which a knowledge of mathematics, chemistry and other natural sciences gained by study, experience and practice is applied with judgment to develop economic ways of using materials and energy for the benefit of mankind.

Occupational Definition Chemical Engineering is a broad discipline dealing with processes (industrial and natural) involving the transformation (chemical, biological, or physical) of matter or energy into forms useful for mankind, economically and without compromising environment, safety, or finite resources.

Chemical engineering is a broad discipline based on chemistry, mathematics, physics and biology that applies the principles of engineering science and process systems engineering to the development and commercialization of new products and processes

2.- Context: Chemical Engineering

The future of Chemical Engineers in Europe

- High average age and high ratios of ChemE´s in the chemical industry

- The chemical industry has a highly-trained and well-educated workforce, which redistributes part of its profits to employees via high-wage, competitive salaries.

- The success of the EU chemical industry depends on its well-trained employees. Skills and education are an important factor in international competitiveness and the EU chemical industry is facing a global challenge for talent.

- Wide range of responsibilities in new & existing processes: Design, production, R&D, technical application, operational research, construction & installation, giving advice to clients and employers.

2.- Context: Chemical Engineering

Energy ⇒ **Golden Opportunity for Chemical Engineers who *are in good position to work in this area***

- **Energy Demand Growing**
    - **Particular growth of renewable energies**
- **Increase in energy efficiency**
- **Development of new technologies**

⇒ ***Need Process Innovation !!***

European Environment Agency: http://www.eea.europa.eu/themes/energy
Intergovernmental Panel on Climate Change: https://www.ipcc.ch/

2.- Context: Chemical Industry

• The chemical industry's contribution to the EU GDP amounts to 1.1 %.

• The EU chemical industry comprises 29,000 enterprises, 96% < 250 employees and are considered as small and medium-sized enterprises (SME). These account for 28% of sales and 35% of employment.

<u>Changes in the chemical industry working environment</u>

The nineties		Current circumstances
Companies stable	⟺	Continuous changes / segregations / consolidations
Lifelong employment	⟺	Better employment / quality of life ratio. High staff turnover
Employment stability	⟺	Constant uncertainty
Fixed workplace	⟺	Mobility
Seniority	⟺	Results / productivity

http://www.cefic.org: Facts and Figures - Full Reports and Slides

2.- Context: Chemical Industry

Future of the European Chemical Industry

Short term

- Impact of the economic and financial crisis
- Low capacity utilization
- Rationalization / factories closing
- Costs reduction
- Continuous adjustment of corporate structures to the needs of the marketplace.

Medium/Long term

- Important market (EU 500 MM inhabitants)
- Wide range of products and operation scales
  * Batch process: specialty chemicals + flexibility + close to the consumer market
  * Continuous process: economy of scale
- High R&D spending → new technologies → innovation as factor of competitiveness.
- Sustainability: new technologies and products
- New structures according to the supply chain and capital sources. Globalization.

The chemical industry will be a key sector in the European economy with continuous adjustment processes

2.- Context: Process System Design

- Success

Ideas → Projects → Products → Market → Success

Nº: ?? Nº: ?? Nº: ?? Nº : ?? 1

- What are the essential elements for success?

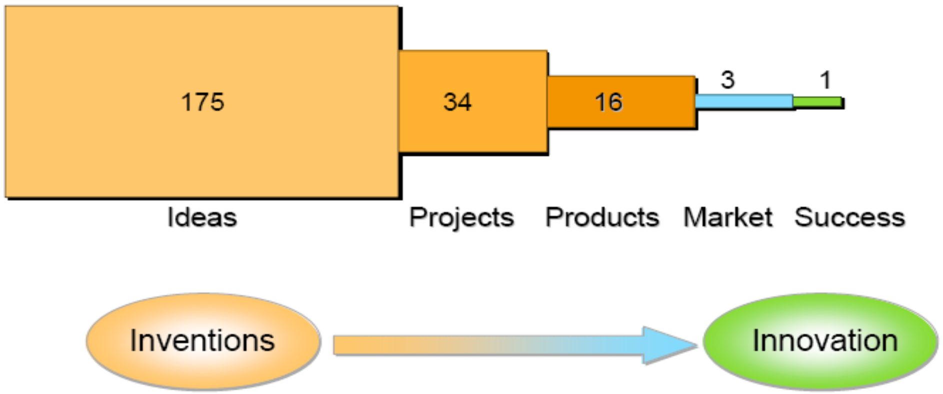
- Element 1
- Element 2
- Element 3

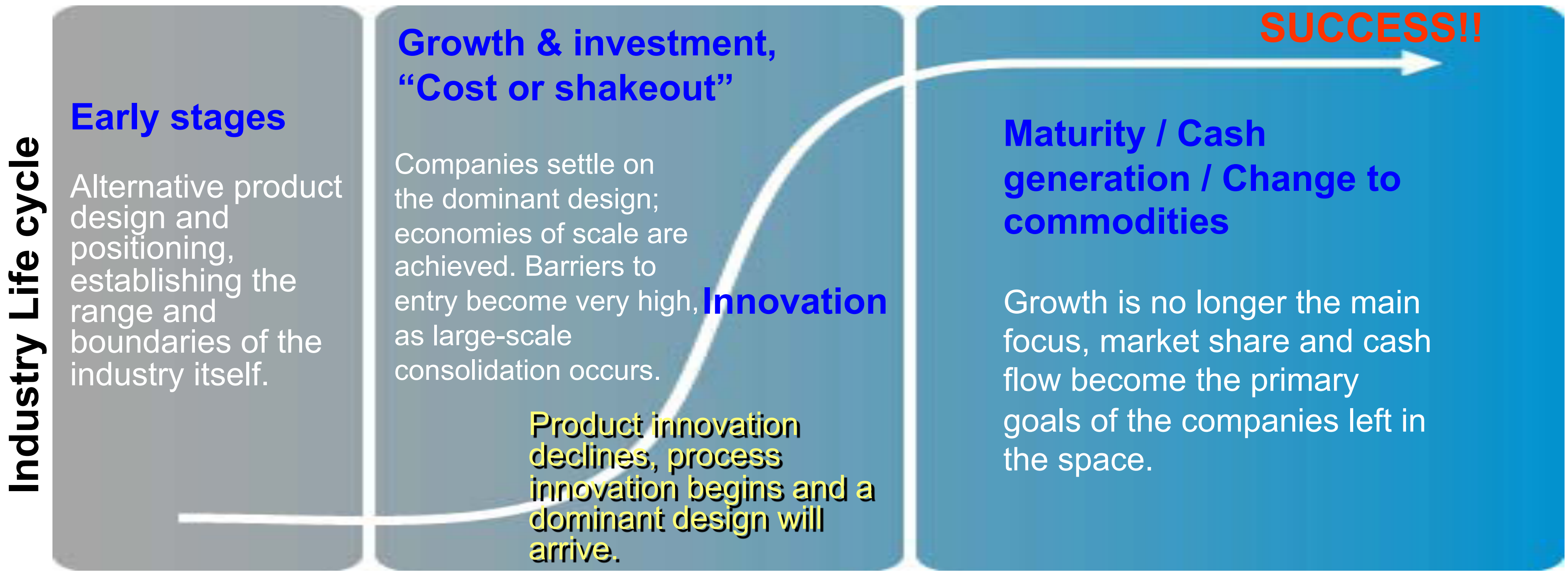
.

.

- Element N

2.- Context: Chemical Engineering





2.- Context: Chemical Engineering

SUCESS requires access to four essential elements

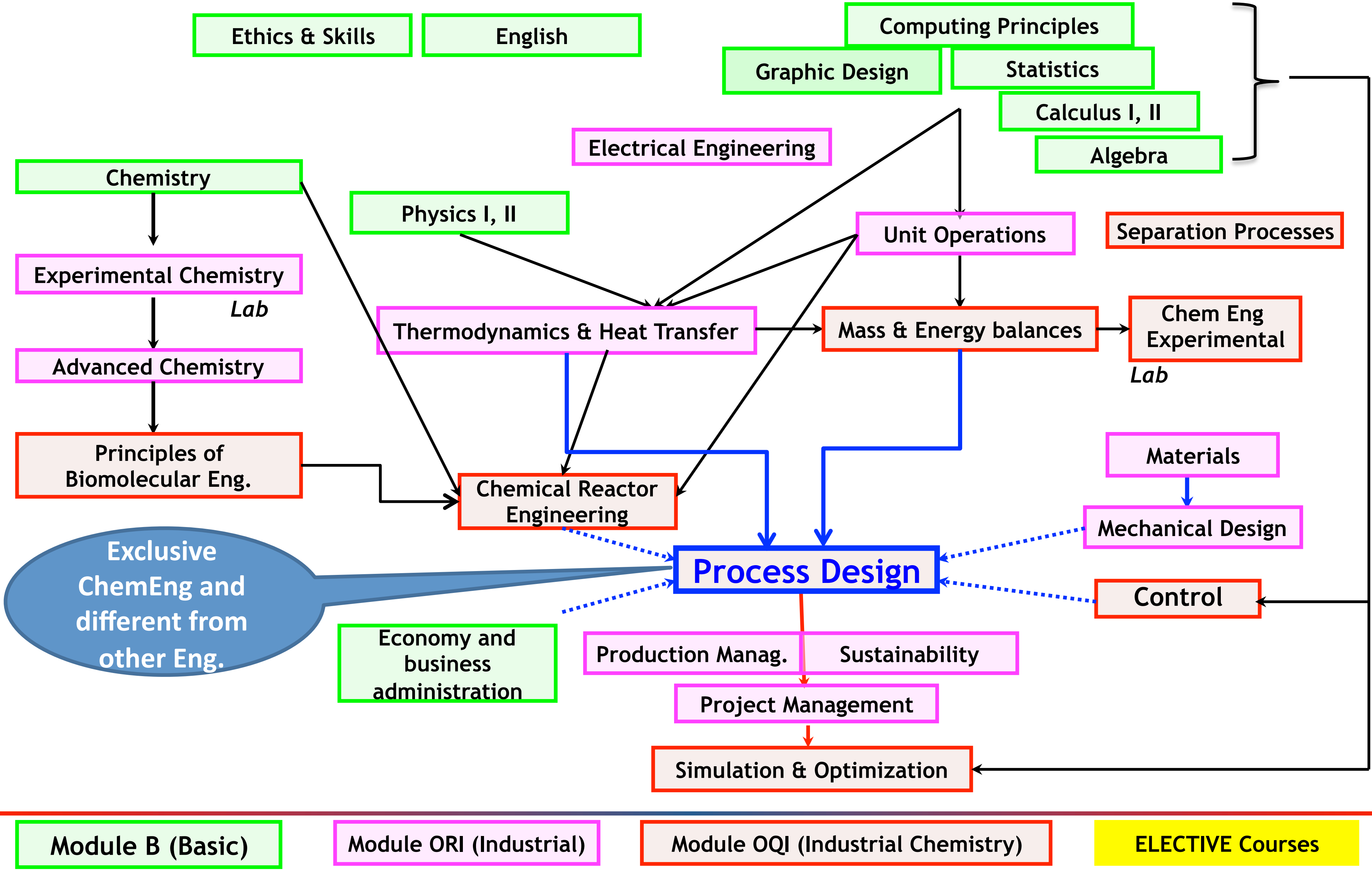
- The developed Nations have limited growth:

Developed Nations 2-3% GDP growth and 14% population vs.
Developing Nations with 6-7 % GDP growth and 86 % population

- The more densely-populated countries have no basic feedstock

- The more feedstock-rich countries have no consumers
15 Countries with 80% of Oil & Gas, only have 12% of the world population

2.- Chemical Engineering Degree (UC)



2.- Context: Chemical Engineering

Chemical Engineering and its Areas (3´50):

https://www.youtube.com/watch?v=maoWixpcMm4

- Appreciate the differences and similarities between engineering disciplines

2.- Context: Chemical Process Design

Basic subjects | **Industrial subjects** | **Industrial Chemistry subjects**

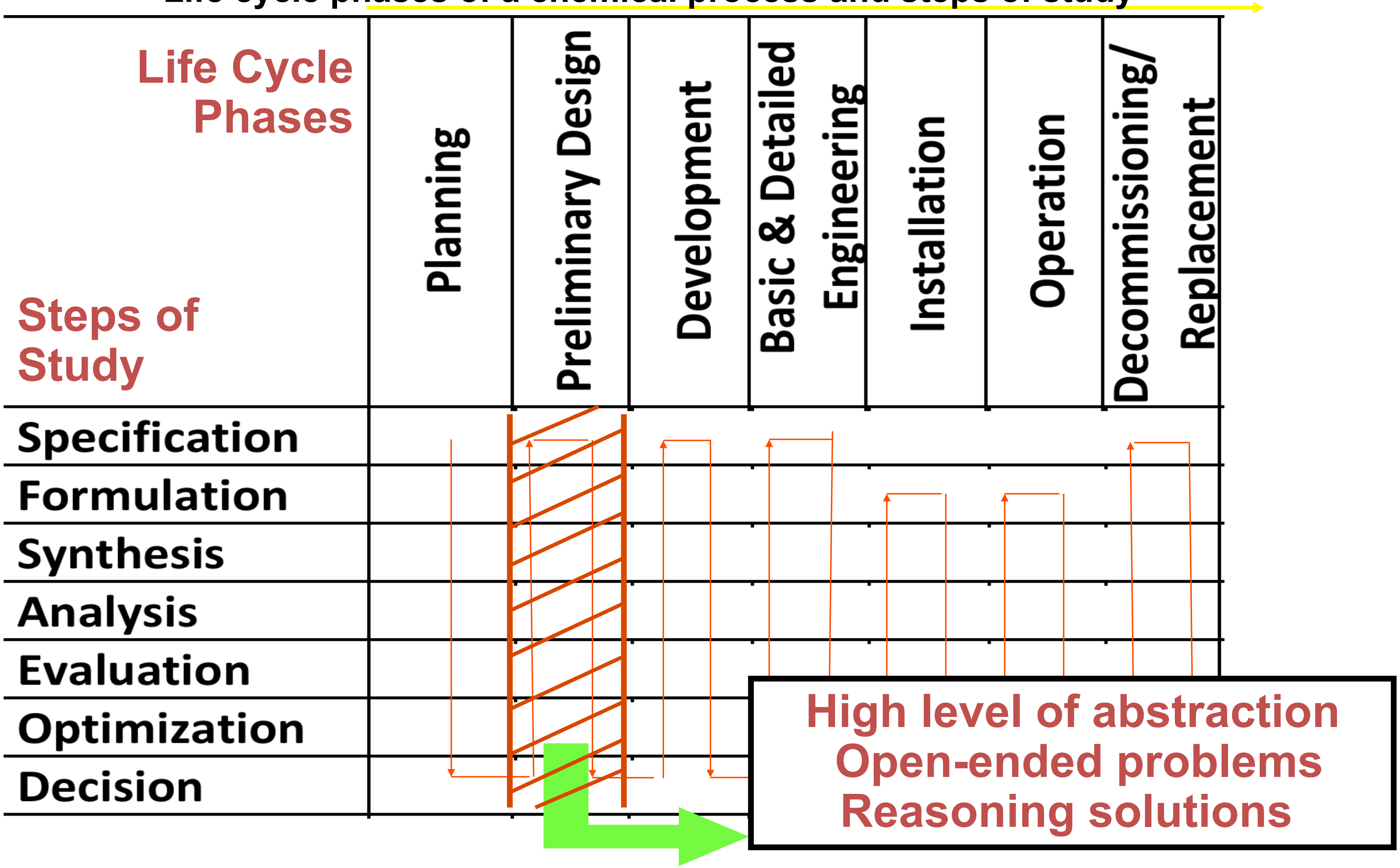
CHEMICAL PROCESS DESIGN

This course introduces students to the methods and background knowledge required for the conceptual design of continuously operating chemical plants. Particular attention is paid to the use of modern design approaches that are used in industry and to problems of current interest. Each team of students is assigned the synthesis, design and evaluation of an industrial project and the preparation of three consecutive design reports and an oral presentation.

More “practical” than previous courses: industrial relevance.
Put together your previous knowledge and actual learning.

2.- Context: Chemical Process Design

Life cycle phases of a chemical process and steps of study



2.- Context: Chemical Process Design

Preliminary Design

Design: Conceiving a device or system to serve an end

Specific Characteristics

- Major emphasis is placed on decision-making
  - Synthesis strategies for generating alternatives
- Learn to deal with simplified analysis models
  - "Taming" complexity
- Learn to make "educated guesses"
  - Incomplete information
- Learn how to screen alternatives
  - Multiple criteria. Economics major criterion

Creativity

Synthesis

Working in a Group

3.- Course outcome objectives

Chemical Engineering Degree Abilities	Course-Specific Objectives	Mechanism
Industrial Chemistry Specific Abilities (CTQ)		
CTQ-2: Ability to **analyze, design,** simulate and optimize **processes and products**	Conceptual design of process flowsheet in group project – open-ended project for industrial process; synthesis of distillation sequences and heat exchanger networks	Lecture, videos, homework and project memos
Ability to identify, formulate and solve engineering problems	To formulate and solve mass & energy balance and design equations for process flowsheets; to formulate equations for process and economic evaluation	Lecture, videos, homework
Ability to design experiments/interpret data	Empirical shortcut equations for evaluation and sizing; graphical representation of data: compression and refrigeration	Videos. Homework and project memos

3.- Course outcome objectives

Chemical Engineering Degree Abilities	Course-Specific Objectives	Mechanism
General Abilities (CG)		
CG-2: Knowledge of **basic and technological** subjects, to learn **new methods and theories,** and to gain **versatility** to adapt new and changing situations **Conveyance and application of math, science, engineering knowledge**	Mass balances, shortcut design calculations; thermodynamic property relations, interest calculations;	Lecture, videos, homework

3.- Course outcome objectives

Chemical Engineering Degree Abilities	Course-Specific Objectives	Mechanism
Transversal Abilities (CT) & Complementary (CC)		
CT-3: Ability to communicate effectively	Three engineering reports required for the design project; oral presentation of the project	Memos; oral Presentation. Co- and Self-evaluation
CT-5: Ability to use modern engineering tools	Excel; AspenPlus, web site	Use in lecture and homework; communication
CT-9: Ability to function in multidisciplinary teams	Design groups for project; informal collaboration in homework	Videos, Homework and memos
CT-16: Understanding of ethics	Design project; discussion on safety and environmental issues	Homework and Memos. Co- and Self-evaluation
CT-17: Appreciation and capability for lifelong learning	To understand the importance of decision-making with limited information; CRC Handbook, Perry's Handbook, extensive literature in process technology, web-resources; industrial speakers	Places to find process information and properties; talks by industrial visitors

3.- Course outcome objectives

Chemical Engineering Degree Abilities	Course-Specific Objectives	Mechanism
Transversal Abilities (CT) and Complementary (CC)		
CT-17: Knowledge of contemporary issues	CO_2 management; excerpts from chemical engineering magazines on processing technology and economic market; industrial speakers	Discussions in lecture
CT-26: Ability to understand impact of engineering in a global/ societal context	Design project related to energy issue: economic and environmental impact	Homework and memos
CC-1: Develop Intuition	To question orders of magnitude, signs, trends, cause-effect relationships.	Lecture and Homework

3.- Course outcome objectives

Students ability and training to be obtained as results:

Synthesis of chemical process working with incomplete information; equipment sizing and process costs estimation; decision-making about the process continuity using evaluation criteria.

- Learn Preliminary Design
- Select Process flowsheet
- Mass and energy balances
- Sizing and economic evaluation
- Process synthesis distillation, heat recovery
- Batch processing

4.- Course syllabus

PART I: INTRODUCTION

1. Introduction to Chemical Process System Design

PART II: SYNTHESIS, ANALYSIS and EVALUATION of PRELIMINARY DESIGNS

2. Methodology of conceptual design 3.
Overview of Process Synthesis
4. Analysis by mass and energy linear balances
5. Equipment sizing and costing
6. Economic evaluation

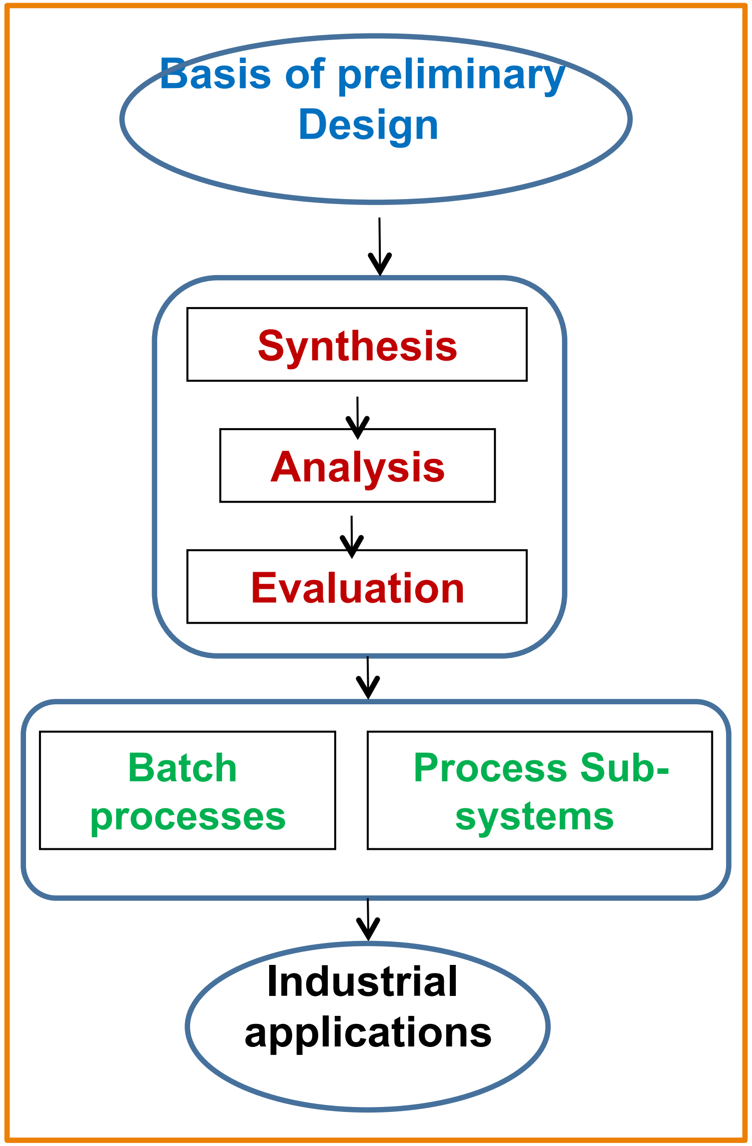
PART III: BASIC CONCEPTS IN PROCESS SYNTHESIS

7. Process synthesis: Distillation
8. Process synthesis: HENS

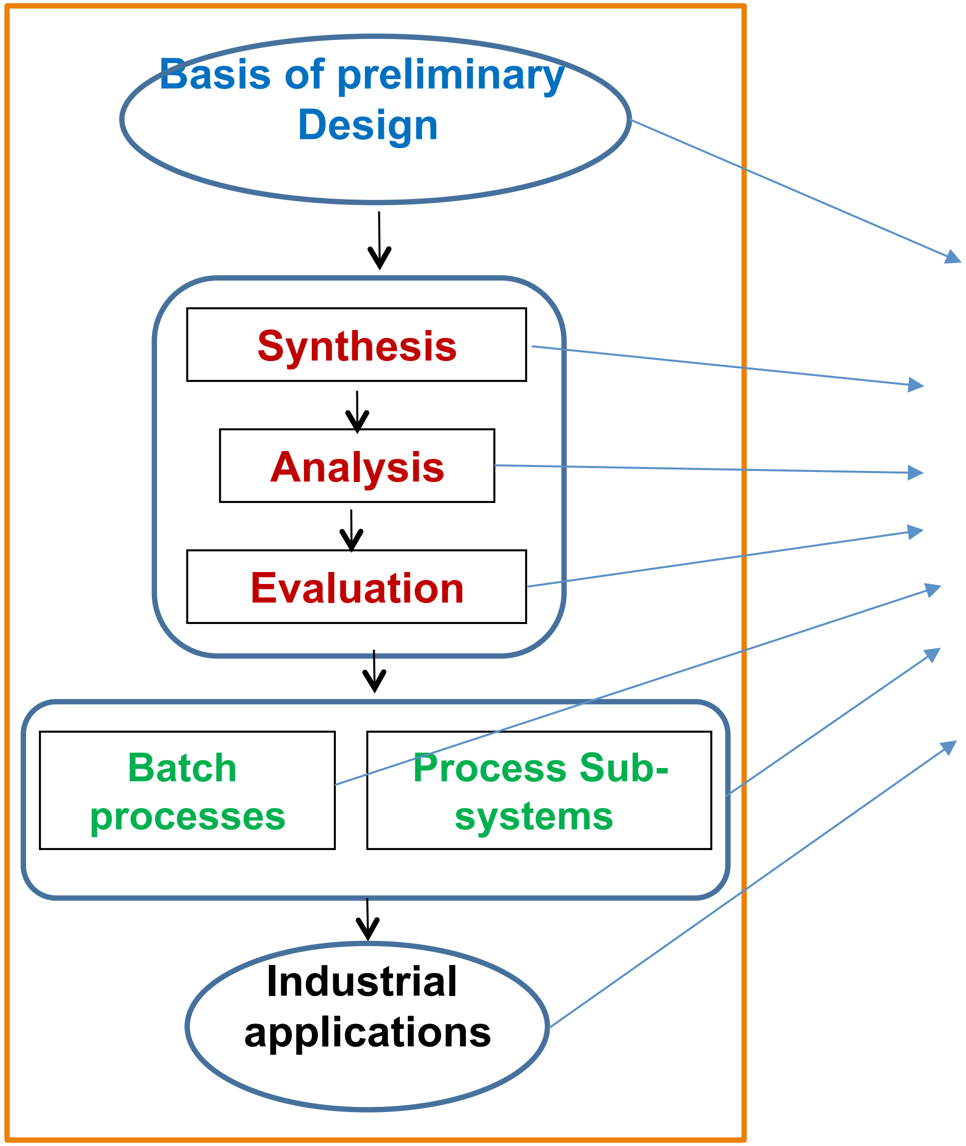
PART IV: BATCH PROCESSES

9. Design and scheduling of batch processes

PART V: APPLICATIONS: Homework, Project, Industrial Conferences



4.- Course syllabus



Key words for each ?

Discuss possible key words for each item in groups of three.

Write the key words down on a sheet of paper.

One speaker in the group explains the keywords

4.- Course syllabus

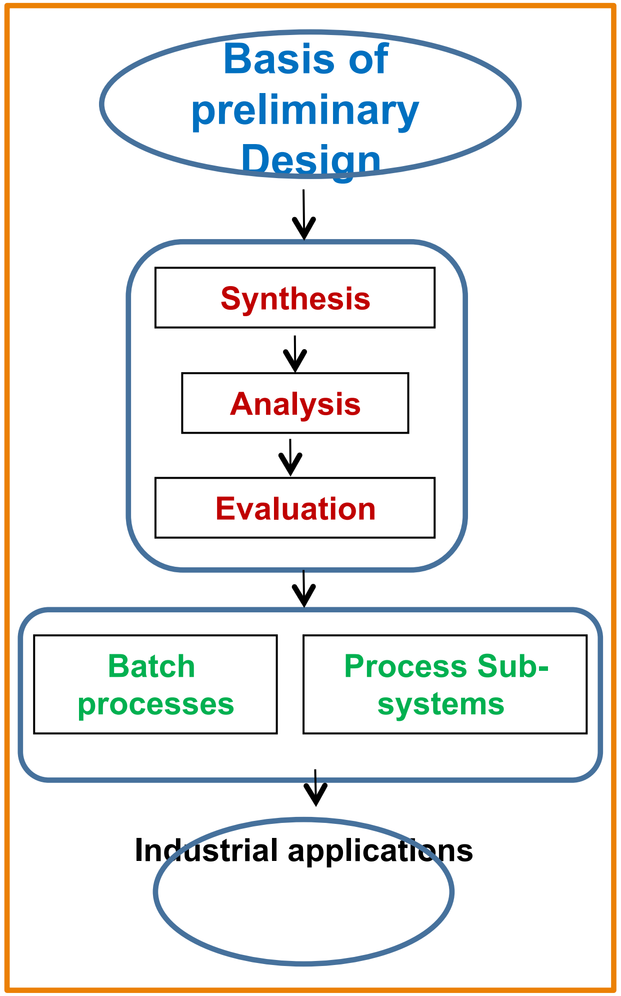
PART I: INTRODUCTION

Chemical industry factors in design process. General issues in relation to chemical process design. Overview of the steps involved in the design process

Subject 1

1. **Introduction to chemical process system design**

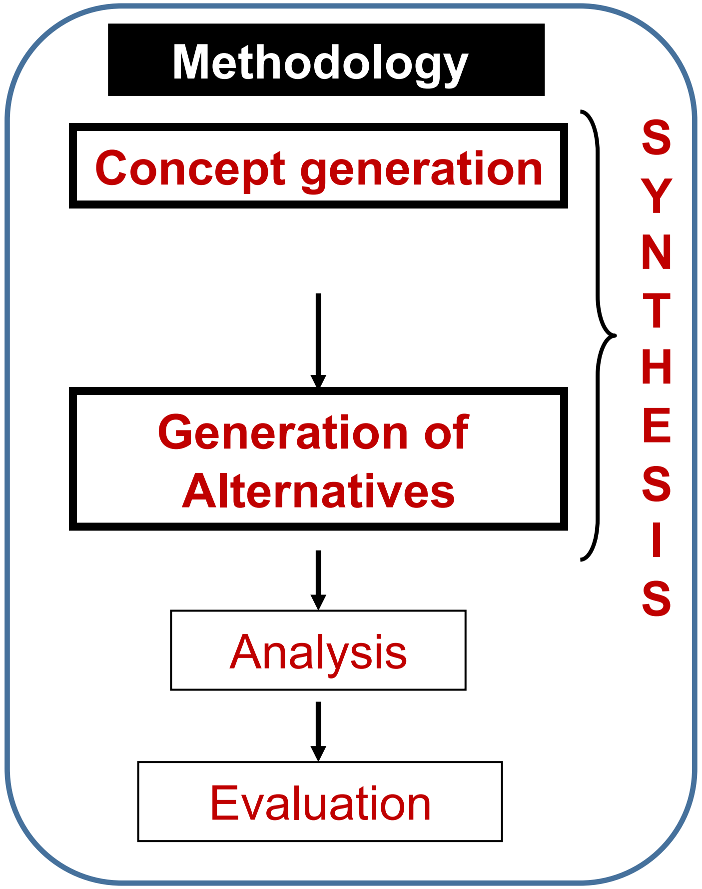
Context
Objectives
Program
Methodology



4.- Course syllabus

PART II: SYNTHESIS, ANALYSIS and EVALUATION of PRELIMINARY DESIGNS

Subject 2-6



2. Methodology of conceptual design

Main characteristics and steps.
Methodology, Tools and Criteria.
Presentation of a Case Study.

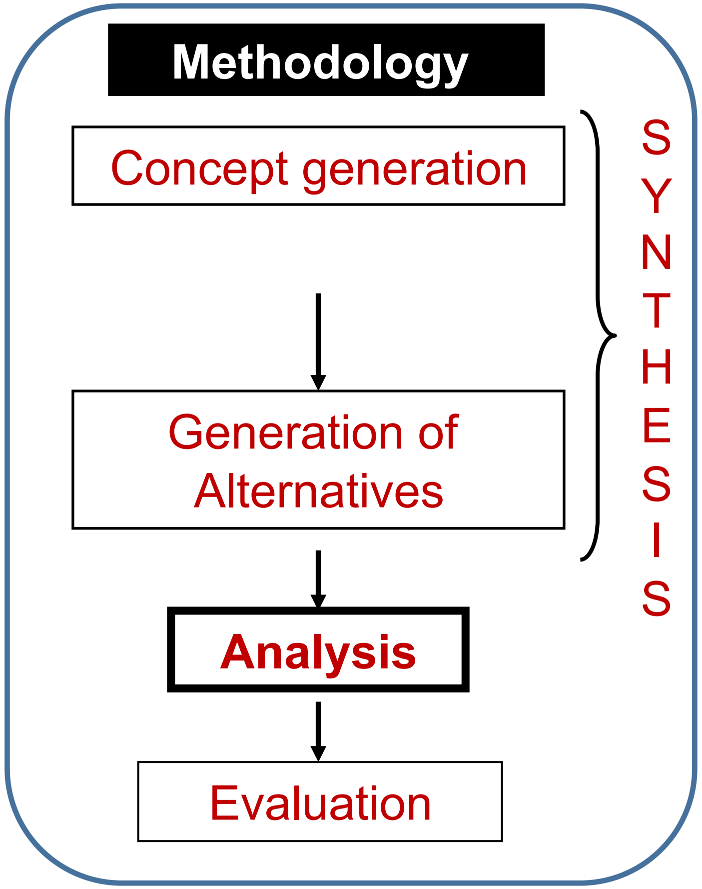
3. Overview of process synthesis

Basic steps in flowsheet synthesis. Generating and searching among alternatives. Decomposition strategies for process synthesis. Hierarchical decomposition of Douglas. Application to a case study.

4.- Course syllabus

PART II: SYNTHESIS, ANALYSIS and EVALUATION of PRELIMINARY DESIGNS

Subject 2-6



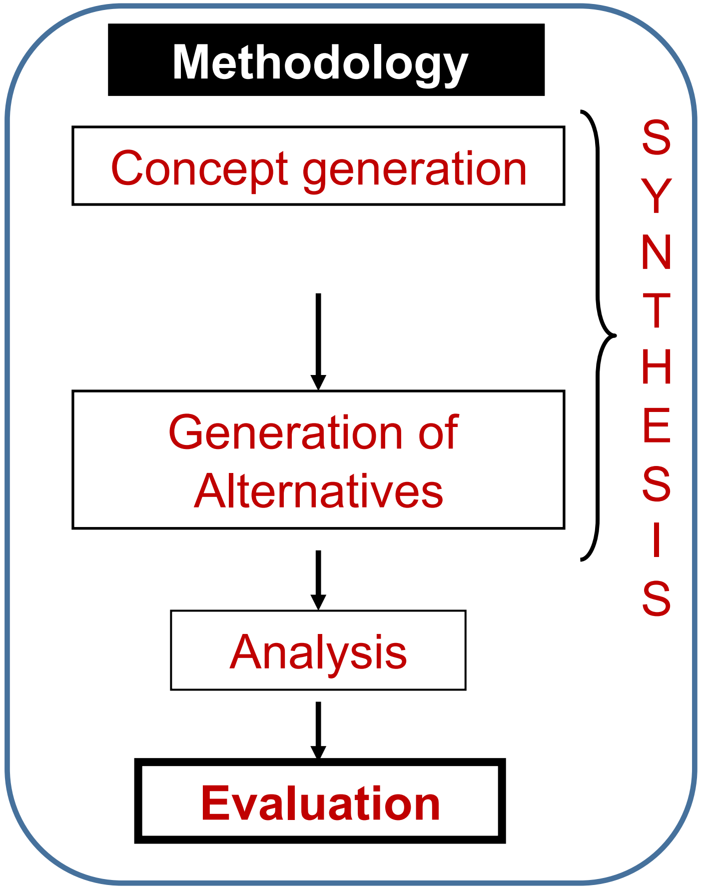
4. Process analysis by mass and energy balances.

Analysis of the inputs effect on the outputs. Methodology for process analysis: Material and energy balances. Models for linear mass balances (LMB). Case Study: Application of LMB algorithm and setting pressure and temperature levels in flowsheet. Heat Balances.

4.- Course syllabus

PART II: SYNTHESIS, ANALYSIS and EVALUATION of PRELIMINARY DESIGNS

Subject 2-6



5. Equipment sizing and costing to a preliminary process design.

Equipment sizing procedures. Costs estimation. Guthrie´s modular method.

6. Economic Evaluation

Economic aspects of the preliminary design. Cost Estimates. Capital Investment. Manufacturing cost. Simple measures to estimate earnings and return on investment. Profitability Measures.

4.- Course syllabus

PART III: BASIC CONCEPTS IN PROCESS SYNTHESIS

Subjects 7-8

Process Subsystems Synthesis

7. Process synthesis: Distillation

Process synthesis. Synthesis of distillation sequences

8. Process synthesis: Heat Exchanger Network Synthesis (HENS)

HENS Introduction. Minimum Utility Consumption. Minimum Number of Units. Optimum approach temperature. Heat Integration.

Case Study

4.- Course syllabus

Renewed interest in batch processes to manufacture high added-value products in flexible plants close to the market

PART IV: Batch Processes

Subject 9

9. Design and scheduling of batch processes

Batch processes characteristics. Single Product Batch Plants: Example, Scheduling by Gantt chart. Multiple Product Batch Plants: Campaigns. Transfer Policies. Parallel units and Intermediate storage. Synthesis of flowshop plants. Sizing of vessels in batch plants. Inventories.

4.- Course syllabus

The practical approach of the Chemical Process Design subject

PART V: APPLICATIONS

ACTIVE LEARNING APPROACH: **Use of "flipped classroom" tactics, Co-and self-evaluation, Virtual Learning Environment**

Project Design → MEMOS

Preliminary design and cost estimate of an bioethanol production plant

Individual Homework. Industrial Conferences.

Application of preliminary design methodology to a process design case study

OTHER RELATED SUBJECTS in the ChemE degree

Simulation and Optimization of Chemical Process Project Management

4.- Course syllabus

ACTIVE LEARNING APPROACH

Qué es el flippedclassroom o clase invertida ? *In Spanish (4´27)*

https://www.youtube.com/watch?v=R16HT9oeg9I

Salman Khan TED 2011. "Reinventar la educación" *In English subtitled in Spanish (20´27)*

https://www.youtube.com/watch?v=CF_oTCspzE8

5.- Course methodology: Academic methodology and organization

ACTIVITIES	HOURS OF THE SUBJECT		
Face-to-face Activities (A)			
- Lectures (TE)	15.00		
- Practical classes (PA)	15.00		
- Team work in computer room (PL)	30.00		
Sub-Total Class hours		60.00	
Supervision Activities (B)			
Tutorials (TU)	15.00		
Assessment (EV)	10.00		
Sub-Total Supervision Activities		25.00	
TOTAL FACE-TO-FACE ACTIVITIES – Contact hours (A+B)			85.00
Non-contact activities			
Team work (TG)		40.00	
Individual work-self study (TA)		25.00	
TOTAL NON-CONTACT ACTIVITIES			65.00
TOTAL			150.00

90 / 60 = 1.5 h /1 h (team + personal work / class)

- **Lectures and Practical work (classroom / computer room),** face-to-face, lectures and applied activities to manage case studies, homework and project memos, guided by teaching staff, in order to achieve expected learning outcomes.
- **Tutorials (seminars, projects),** personal student supervision.
- **Individual and Group work,** Preparation beforehand and finalizing notes after attending a lecture, seminar or laboratory work; collection and selection of relevant material; required revision, study of that material; writing of homework/projects/dissertation; practical work, (e.g. in a computer room). Time required to prepare for and undergo the assessment procedure (e.g. exams); time required for obligatory placement(s).
- **Assessment,** examinations, written project memos and oral presentations and written homework used to evaluate learners' achievement of expected learning outcomes.

All of them in a Learning Outcome context: Statements of what a learner is expected to know, understand and be able to do after successful completion of a learning process.

6.- Course assessment / marks

Exam:	**40 points**
Memo 1 + Memo 2 + Memo 3 +	**48 points**
Oral Presentation [Full project] + Seminars:	**12 points**
TOTAL :	**100 points**

Groups 3 - 4 students

The **minimum average mark** required for both of the two partial exams will be 4 out of 10 in order to access the continuous assessment method. In order to be able to consider the mark of the Memos and Seminars, it is necessary to **attend the scheduled Conferences**, attend at least **90% of the practical classes** and **deliver the work** on the dates indicated.

Check the Course Academic Guide

The characteristics of the Process Design Course make necessary a student Trade Management* approach.

(*) business process by which manufacturing companies manage their trade promotions, budgets, claims and deductions, and indirect sales.

7.- Textbooks

Evolution of the Teaching of Process Design:

From traditional courses ***focused on detailed design and relying on experience***
Using Traditional Textbooks on Process Design, such as:

Peters and Timmerhaus, 1958; Ludwig, 1964; Baasel, 1976.

TO

Modern approaches to Process Design:

More emphasis on the "big" picture
Relying on systematic procedures
More emphasis on Synthesis
Maximizing the use of computers

Douglas, 1988; Biegler et al., 1997; Seider et al., 2010.

7.- Textbooks

Textbooks particularly recommended

- Biegler, L.; Grossmann, I. & Westerberg, A. (1997): *«Systematic methods of chemical process design»*. Prentice Hall.

- Douglas, J. (1988): *«Conceptual design of chemical processes».* McGraw-Hill.

- Seider, W.; Seader, J.; Lewin, D. & Widadgo, S. (2010): *«Product & process design principles»*. 3rd Ed. John Wiley & Sons.

7.- Textbooks

Other textbooks with modern approaches to Process Design

- Erwin, D. (2014): *«Industrial chemical process design»*. 2nd Ed. McGraw-Hill.

- Martin Martin, M. (2016): *«Industrial chemical process analysis and design»*. Elsevier.

- Sinnot, R. & Towler, G. (2009): *«Chemical engineering design»*. 5th Ed. Coulson & Richardson´s Chemical Engineering Series. Elsevier.

- Sundmacher, K.; Kienle, A. & Seidel-Morgenstern, A. (Eds) (2005): *«Integrated chemical processes. Synthesis, operation, analysis and control»*. Wiley-VCH. 2005.

- Turton, R.; Bailie, R.; Whiting, W. & Shaeiwitz, J. (2003): *«Analysis, synthesis and design of chemical processes».* Prentice Hall PTR. 2003.

7.- Textbooks

Economic Aspects

- Peter, M.; Timmerhaus, K. & West, R. (2005): *«Plant design and economics for chemical engineers».* 5th Ed. McGraw-Hill.
- Valle-Riestra, J. (1983): *«Project evaluation in the chemical process industries».* McGraw-Hill.

Rules of Thumbs

- Branan, C. (Ed.) (2005): *«Rules of thumbs for chemical engineers»*. 4th Ed. Elsevier.
- Jones, D. (1997): *«Elements of chemical process engineering».* John Wiley & Sons.
- Ulrich, G. & Vasudevan, P. (2004): *«A Guide to chemical engineering process design and economics»*. 2nd Ed. John Wiley & Sons.

7.- Textbooks

Product design

- Achenie, L.E.K.; Gani, R. & Venkatsubramanian, V. (2003): *«Computer-aided molecular design: theory and practice»*. Computer Aided Chemical Engineering, 12.
- Cooper, R.G. (2002): *«Winning at new products: accelerating the process from idea to finish»*. 3rd Ed. Perseus Publ. Cambridge, MA.
- Cussler, E. & Moggridge, G. (2001): *«Chemical product design»*. Cambridge. University Press.
- K.M. Ng; R. Gani & K. Dam-Johansen (2007): *«Chemical product design: towards a perspective through case studies»*. Elsevier.
- Wei, J. (2007): *«Product engineering - Molecular structure and property»*. Oxford University Press.

7.- Textbooks

CACHE Process Design Case Study Series

(http://cache.org/super-store/cache-process-design-case-studies)

- **Vol 1.** Separation system for recovery of ethylene and light products from a Naphtha pyrolysis gas steam.
- **Vol 2.** Design of an ammonia synthesis plant.
- **Vol 3.** Design of an ethanol dehydrogenation plant.
- **Vol 4.** Alternative fermentation processes for ethanol production and economic analysis.
- **Vol 5.** Retrofit of a heat exchanger network and design of a multiproduct batch plant.
- **Vol 6.** Chemical engineering optimization models with GAMS.
- **Vol 7.** Design of an ethylbenzene production plant.
- **Vol 8.** Nitrogen from air (version on-line).
- **Vol 9.** Conceptual Design of Second Generation Bioethanol Production via Gasification of Lignocellulosic Biomass.
- **Vol 10.** Conceptual Design of the supply chain and production facility of lignocellulosic bioethanol via hydrolysis.
- **Vol 11.** Conceptual Design of an Aromatics Plant from Shale Gas.

7.- Textbooks

Textbooks in Spanish

- Branan, C. (Ed.) (2000): *«Soluciones prácticas para el ingeniero químico»*. 2ª Ed. McGraw-Hill.
- Diaz, M. (2012): *«Ingeniería de bioprocesos»*. Ediciones Paraninfo.
- Happel, J. & Jordan D. (1981): *«Economía de los procesos químicos»*. 2ª Ed. Reverté.
- Jimenez-Gutierrez, A. (2003): *«Diseño de procesos en ingeniería química»*. Editorial Reverté, S.A.
- Puigjaner, L.; Ollero, P.; De Prada, C. & Jimenez, L. (2006): *«Estrategias de modelado, simulación y optimización de procesos químicos»*. Editorial Síntesis.
- Ravagnani, M. & Caballero, J.A. (2012): *«Redes de cambiadores de calor»*. Publicaciones de la Universidad de Alicante.
- Roberts, R. & Serendipia (2010): *«Descubrimientos accidentales en la ciencia»*. Alianza Ed.
- Sinnot, R. & Towler, G. (2012): *«Diseño en ingeniería química»*. Editorial Reverte.

7.- Textbooks

Encyclopedias and Handbooks on Chemical Engineering

- Kirk, R.E. & Othmer, D.F. (1961): *«Encyclopedia of chemical technology. Enciclopedia de tecnología química»*. México. Unión Tipográfica Ed. Hispano-Americana.

- Mcketta, J.J. & Cunningham, W.A. (1976-2002): *«Encyclopedia of chemical processing and design»*. New York. Marcel Dekker.

- Ullmann, F. (1999): *«Ullmann's encyclopedia of industrial chemistry»*. 6th Ed. Electronic release. Weinheim. Wiley-Vch.

7.- Other Resources

- AIChE, American Institute of Chemical Engineers: http://www.aiche.org.
- Reference documents (BREF). European IPPC Bureau (EIPPCB). European Commission's Joint Research Centre (JRC): http://eippcb.jrc.es/reference/.
- CACHE: http://www.che.utexas.edu/cache/casestudy.html.
- European Chemical Industry Council (CEFIC): http://www.cefic.org.
- Chemical Engineers Salaries: http://www.worldsalaries.org/engineer.shtml.
- European Federation of Chemical Engineering (EFCE): http://www.efce.info.
- Federación Española de Ingenieros Químicos (FEIQ): http://www.feiq.es.
- Federación Empresarial de la Industria Química Española (FEIQUE): http://www.feique.org/.
- GlobalSpec. Products and services catalogue: http://search.globalspec.com.
- Institution of Chemical Engineers (IChEME): http://www.icheme.org.
- SusChem, 2009. The European Technology Platform for Sustainable Chemistry. IAP Update 2009. Reaction & Process Design: http://www.suschem.org.
- The Tubular Exchanger Manufacturers Association, Inc. (TEMA): http://www.tema.org.
- World Chemical Engineering Council (WCEC): http://www.chemengworld.org/First_Project.html.

7.- Bibliography for this subject

- **«Chemical engineering plant animation design» (5´07):**
  https://www.youtube.com/watch?v=ah6_GJqD048.

- **Subject matter:**
  - List of equipment and number of each piece of equipment.
  - Kinds of Utilities.
  - Is there a recycle loop?

- **«Historia de la Química X. El auge de la industria» (in Spanish) (22´33):**
  https://canal.uned.es/mmobj/index/id/12244.

- **Cuestiones:**
  - Motivaciones del desarrollo de la Industria Química.
  - Indicar las reacciones de cada proceso industrial descrito.

- **«Entrevista Avelino Corma» (in Spanish) (1´41):**
  http://www.elmundo.es/ciencia/2014/07/14/53c042dcca4741eb4b8b45a0.html.

- **Cuestiones:**
  - Áreas industriales de actuación.
  - Ecuaciones relacionadas con la Innovación.

RELEVANT TO LEARNING

- **Process from inventions to innovation: Steps, success rate, industry life cycle curve.**

- **Essential elements to achieve success in industrial chemistry production.**

- **Steps of study during the life cycle phases of a chemical process: Steps, phases, application.**

- **Name and justify a list of specific characteristics of the preliminary Process Design.**

- **List and match the characteristics of the chemical industry that determine the characteristics of chemical process design? What is the reason for this relationship?**