What is Chemical Engineering ?

You are majoring in Chemical Engineering and have been chosen to return to your high school and recruit the *best and the brightest* to follow in your footsteps. How would you explain your newfound profession and convey an idea regarding the types of tasks others may encounter in the ChE job market ?

- Explain the role of a ChE in "traditional" contexts
  - # Define and give examples of a process (or ChE process)
  - # Identify tasks a ChE would perform in a given industry / situation
- Explain the role of a ChE in emerging markets
  - # Distinguish between product and process design / analysis
  - # List the steps involved in product design
- Identify the tools used in process design / analysis
  - # Define the term balance equation and give examples of things that might be balanced
  - # Describe the characteristics and purpose of a flowchart
  - # Identify a valid flowchart for a given process description

So you want to become a Chemical Engineer (ChE)...

What am I getting myself into?

No well accepted definition of what a chemical engineer is, because people who call themselves ChE's do so many things!

Let's try anyway...

DEFINITION:

> *A **ChE** is a person who: (1) develops or designs a new process or product; (2) **re-**designs, improves, or troubleshoots a process/product, in order that it is accomplished as economically, safely, and efficiently as possible.*

But this is so general?!

- 45% do "traditional" ChE: chemical, petroleum, plastic, paper, consumer goods
- 35% "new" ChE: environment, consulting, microelectronics, biotech, materials
- 10% go to ChE graduate school
- 10% go to other graduate school (law, medicine, business)

Ok, so what do we mean by "process"?

Again, we will start with something general (because how else can we cover this broad field):

DEFINITION:

> *A **process** is any operation (or group of operations) which allow something to be accomplished.*

For **most** ChEs, we can be slightly more specific:

DEFINITION:

> *A **chemical engineering process** is a process that takes one material or bit of energy (or a combination) and makes from it another material or bit of energy (or combination).*

OUTCOME:

> Define and give examples of a process (or ChE process)

TEST YOURSELF!

> *Give some examples of "processes" from everyday life. Name a ChE process.*

NOTE:

> *Green links/text will always correspond to "test yourself" exercises.*

How about some examples...

As we mentioned before, a ChE may do lots of different things. While it would take us too long to discuss **all** of the posibilities, examining two "typical" examples might help you to extrapolate (we will earn this word later!) to other scenarios.

Two "typical" things that a chemical engineer might do:

EXAMPLE:

*Your friend is a baker and wants to start a cookie company. He/She asks you to help him/ her make the transition to the **big time** (since you are a chemical engineer, of course). You are given the basic recipe for the cookies (flour, water, sugar, eggs) and told that all that you need to do is mix this and heat. Several (OK, **more** than several, but we will only look at several) important questions arise with these new circumstances that your friend simply **cannot** answer by himself/herself:*

- What type of mixer should we use? (We can no longer "hand-mix" if our batch is 1000 lbs!)
- How much heat is necessary/what type of oven?
- How long will it take (in our new oven)?

This is clearly a very simple example, but it illustrates a few important points:

- consider maintaining economy, efficieny, and consistency (among other things like safety, for example) when you scale a proposed process up
  It seemed silly to picture your friend mixing a huge vat of cookie dough by hand, WHY? [cheat]
- consider the physical properties of the material (cookie dough, here) in order to determine the operating conditions.
  If you set the temperature very high it will cook faster, but it may not be economical or safe!

A more "mainstream" ChE example:

EXAMPLE:

Ethylene Oxide is an important industrial chemical intermediate. A fellow in the chemistry division of your company tells you that reacting ethylene with air will produce this product. It's now your job to figure out how to do this on the production scale.

- Unfortunately, reacting ethylene with air (essentially **burning** the ethylene) will result in the production of carbon dioxide and water, if allowed to go to completion. What type of reactor should be used to try to **stop** the reaction at the intermediate stage (ethylene oxide)?
- This process also generates heat, what temperature should we try to run the reaction? how do we control the temperature? how do we avoid "runaway" (an explosion)?

- If our end goal is to make ethylene glycol (an ingredient in car antifreeze), is it cheaper to build this new process or just **buy** the ethylene oxide in the first place?

We could go on all day with examples (but instead we will go on all **semester**, we will just do the other ones in more detail!).

IMPORTANT:

> These two examples show how ChEs do process design, but a ChE might *also* troubleshoot an existing process, optimize an existing process, etc. (More on these options as we go.)

OUTCOME:

> Identify tasks a ChE would perform in a given industry/situation

TEST YOURSELF!

> *If you went to work for a ketchup manufacturing company, what might some of your tasks be (as a ChE)?*

Process versus Product Design/Engineering.

As mentioned previously, "traditional" ChE's would design/troubleshoot/optimize *processes*. What that means is that someone *else* would tell them:

- what material to make and to what degree of purity (for example: 99% pure acetone)
- the basic chemical steps that should be used to make it (this was the work of the chemist: to determine what mechanistic pathway would work)

This left the ChE to figure out how to scale-up the benchtop chemistry to production, etc. and how to perform any necessary separations, how to do all of this as economically as possible (so that the plant would make money).

DEFINITION:

> ***Process engineering*** *is the practice of designing and troubleshooting processes for materials that are well-defined from the standpoint of both purity and chemical composition (typically commodity chemicals).*

Product design/engineering, in fact, *includes* process design/engineering (we still recognize that you need to *make* the stuff after you design it!), but takes several steps backward toward the "bigger picture". By looking at the bigger picture we now change our focus to:

- what does our customer what their material to *do*: if they wanted 99% pure acetone to use as a solvent to dissolve chemical "B", perhaps their is a better choice of solvent, perhaps they should change "B" so that it dissolves in something else
- the ChE works intimately with the chemist to determine what pathways most easily scale up with a minimum of waste, both environmentally and economically

This is a fundamental shift that has helped ChE's to rapidly move away from purely making commodity chemicals, and to branch effectively into: specialty chemicals, pharmaceuticals, devices (medical, electronic, etc.), consumer goods, and so on.

The Swiffer® (a registered trademark of Procter & Gamble) is a great example of a product designed with significant input from ChE's. Their goal was to make a better dusting cloth. They decided what that cloth would need to be able to *do*, then they came up with materials that could do it, and *then* they designed the process to make it! (more on the product design process soon)

DEFINITION:

> ***Product engineering*** *is the design and manufacturing of (chemically related) products that satisfy specific customer goals, starting from material screening through manufacture.*

OUTCOME:

> Distinguish between product and process design/analysis

TEST YOURSELF!

Come up with some examples of products that ChE's might design.

The Product Design Process

Much of this course will be devoted to tools that aid in *process* design rather than the multidisciplinary nature of product design. Nevertheless, we will touch on product-related issues as we go.

Customer Needs

The first step in product design is identifying what needs the customer is trying to satisfy. This requires extensive communication with customers (or representative groups of potential customers). Interpreting these needs is difficult, as they may conflict! Ranking the needs allows a designer to try to develop (material) specifications from the list on needs.

Generating Ideas

The next step is to brainstorm to compile a large list of potential products to meet the previously identified specifications. Sometimes brainstorming is not enough and more "brute force" methods such as combinatorial chemistry (where one makes *many* candidates -- either virtually of physically -- for testing) is needed.

Selection

Once many ideas are generated, a leading candidate must be selected. In contrast to traditional commodity chemical production, here the best candidate will not necessarily be the cheapest, but instead will balance: economics, suitability for needs, and sustainability (economy of both material and energy resources).

Manufacturing

The last step includes traditional Chemical Engineering *process* design, but now with a much stronger connection to the chemist and other members of the product design team.

OUTCOME:

List the steps involved in product design

ChE: Define the term balance equation and give examples of things that might be balanced

Balance Equations

Imagine the following:

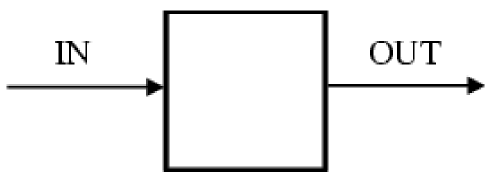
- the US mints all close, so that no new $1 bills are ever generated
- none of the bills ever wears out

If these two things held true, the total number of $1 bills in the world would *never change*. That is, they would be **conserved**.

DEFINITION

*If something is **conserved**, the total number (or amount) never changes.*

If $1 were conserved, then you could easily keep track of how many where in your wallet (or bank account) by simply comparing how much comes in versus how much comes out (we will ignore interest for now).



If both IN and OUT were the same number (or the same *rate* (for example, dollars per hour)), then the total amount of money in your account would always be the same. If IN is bigger than out, you are *accumulating* dollars; if OUT is bigger you are *depleting* your supply (which we will call a negative accumulation).

What we have just done is a simple *balance* on dollars, using the following balance equation:

ACCUMULATION = IN - OUT

DEFINITION

*A **balance equation** is a tool used to account for where things come/go and how their total number (or amount) changes.*

If we now consider interest, it is possible for the total amount in your account to increase without you putting any money in yourself. We will call this *generation*, similarly the bank might change you something for having an account (so the total amount decreases without your taking any out), so that some is *consumed*.

A more general balance equation then, is given as

ACCUMULATION = IN - OUT + GENERATION - CONSUMPTION

OUTCOME:

Define the term balance equation and give examples of things that might be balanced

NOTE:

A balance need not be done **only** on conserved quantities.

NOTE:

In fact, if a material is truly **conserved** generation and consumption must both be zero. In other words, a balance on total dollars in this example could not have generation and consumption. Our example did involve generation and consumption because we were doing a **specific** balance on your money (not total money) so you "generated" dollars by taking them from someone else and "consumed" them by giving them to someone else.

An intro to flowcharts or "How on earth do we actually do all of that?"

Things ChEs do to processes:

- design
- troubleshoot
- analyze
- optimize
- etc., etc.

HOW?! No simple answer!

This course -> general guidelines or recipes. These help you to organize and tackle each unique problem.

Simplest (but at the same time most important) tool: flow diagram, flowsheet, or flowchart.

DEFINITION:

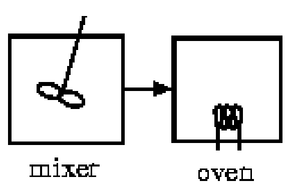
*A **flowchart** is a diagram that completely represents a process (i.e., it includes the process units, process streams, etc.).*

So what are process *units* or *streams*?

Let's consider our bakery example first...

EXAMPLE:

You know that, in its simplest form, your friend's bakery must consist of two steps: a mixing step, and a cooking step. You might represent these two steps like this:



We are now on our way to out first flowchart!

Each of the steps can be thought of as a **process unit** (as you may have guessed).

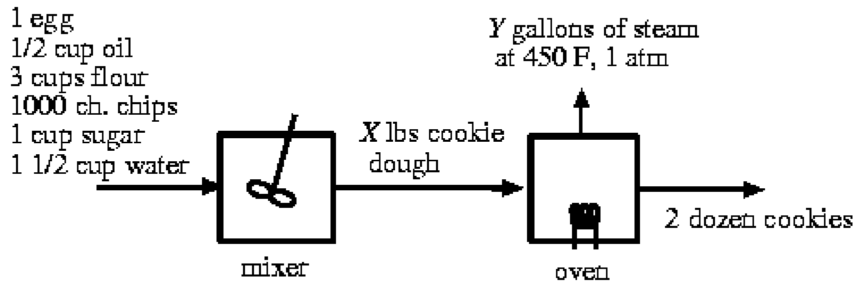
Leaving only **process streams**:

DEFINITION:

*A **process stream** is a line which represents the movement of material to/from process units. Typically these streams are labeled with information regarding the amounts, compositions, temperatures, pressures, etc. of the components.*

So if we now **add** process streams to our diagram from above we will have a valid flowchart:

EXAMPLE (cont.):



Before moving on we should mention a few additional things about our flowchart:

- The streams are labeled in a variety of differing units (cups, gallons, lbs, etc.). We will have to be careful of this as we move on in our analysis (more on this in the next section).
- I thought that we were "scaling-up" this process...why are the quantities still so small?
- Some of the streams have "unknown" quantities listed. These are labeled with variables (x and y) in anticipation of solving for these values (again, we will get to this aspect later).
- Finally, there are funny pictures inside the boxes. What do they mean?

OUTCOME:

Describe the characteristics and purpose of a flowchart.

TEST YOURSELF!

Choose the right flowchart!

Flowchart Exercise

Recall the ethylene oxide example from two lessons ago:

EXAMPLE:

Ethylene Oxide is an important industrial chemical intermediate. A fellow in the chemistry division of your company tells you that reacting ethylene with air will produce this product. It's now your job to figure out how to do this on the production scale.

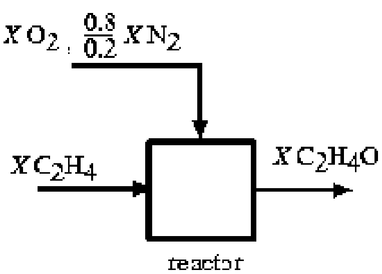
After extensive testing, your design team has come up with a process to fullfill this need and submits it for your approval. As the first step in analyzing their creation, you draw a flowchart of the proposed process. Label as many streams (known and unknown) as possible.

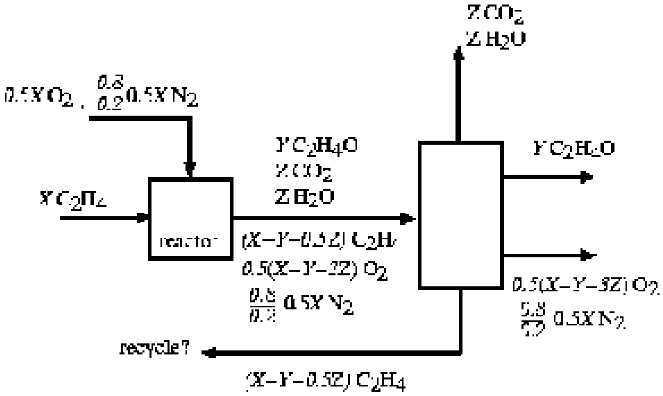
Based on pilot-scale reaction data the design team has determined the following:

- the primary unwanted reaction is the complete combustion of the ethylene to CO_2.
- in order to minimize the formation of CO_2 the concentrations of ethylene (C_2H_4) and oxygen should be kept as low as possible (this will be acheived with an air feed to supply dilute oxygen).
- the products will then contain ethylene oxide, some of the unwanted products, CO_2 and H_2O, and the unreacted O_2, N_2, and C_2H_4.
- we therefore will need to separate the products in order to purify our desired product, as well as to reclaim (and perhaps recycle) our unreacted materials.
- the reaction should be run under stoichiometric conditions (I don't remember what stochiometric means!) [hint].

EXERCISE:

Given the following process description, choose (click) the appropriate flowchart.





From this example you see that there are several necessary components in a valid flowchart:

- All streams must have labels for flow and compositions
- What goes *into* a unit, must come out (except for units undergoing reactions, which we will see later)
- The "skeleton" must match the description (have all the mentioned units, connected by streams in the correct fashion)

OUTCOME:

Identify a valid flowchart for a given process
