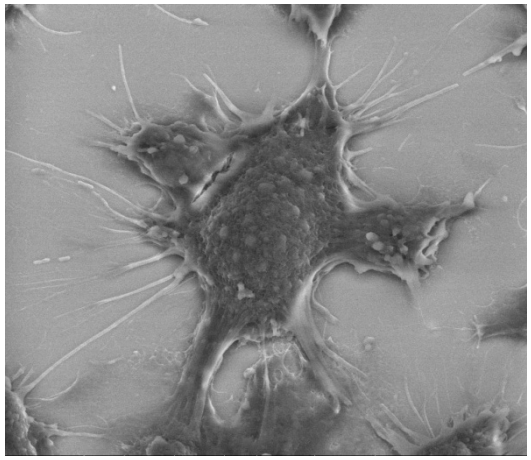
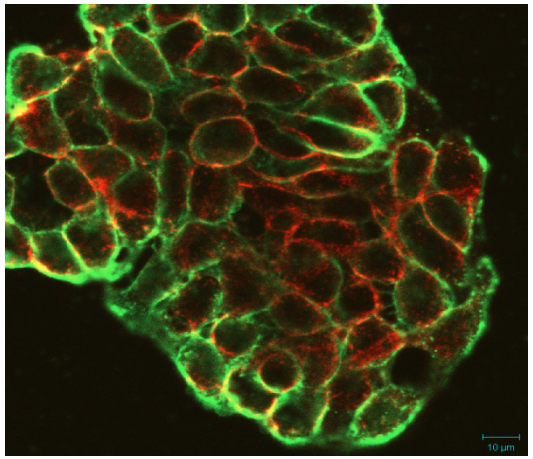
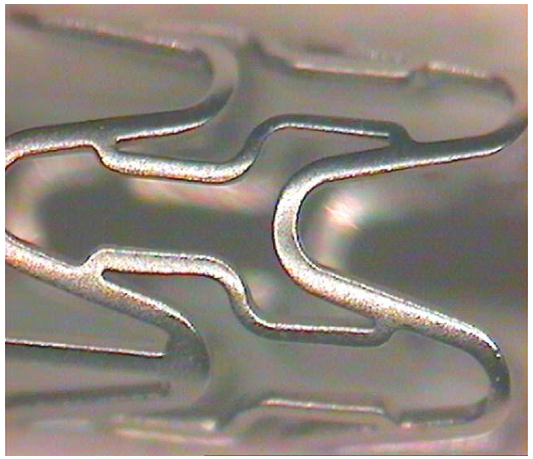
Biological Sciences

B. CHEM. ENGG.







Integration of Biological Sciences in Chemical Engineering : A Seamless Approach

Dr. Ratnesh Jain

The Need For Change

ChE paradigm useful for more than 100 years

Response to industry based on
commodity chemicals(20s), petroleum (30s),
polymers (40-70s), traditional pharmaceuticals

All mature industries- little growth

Chemical engineering is flexible
new technologies accommodated with same core material

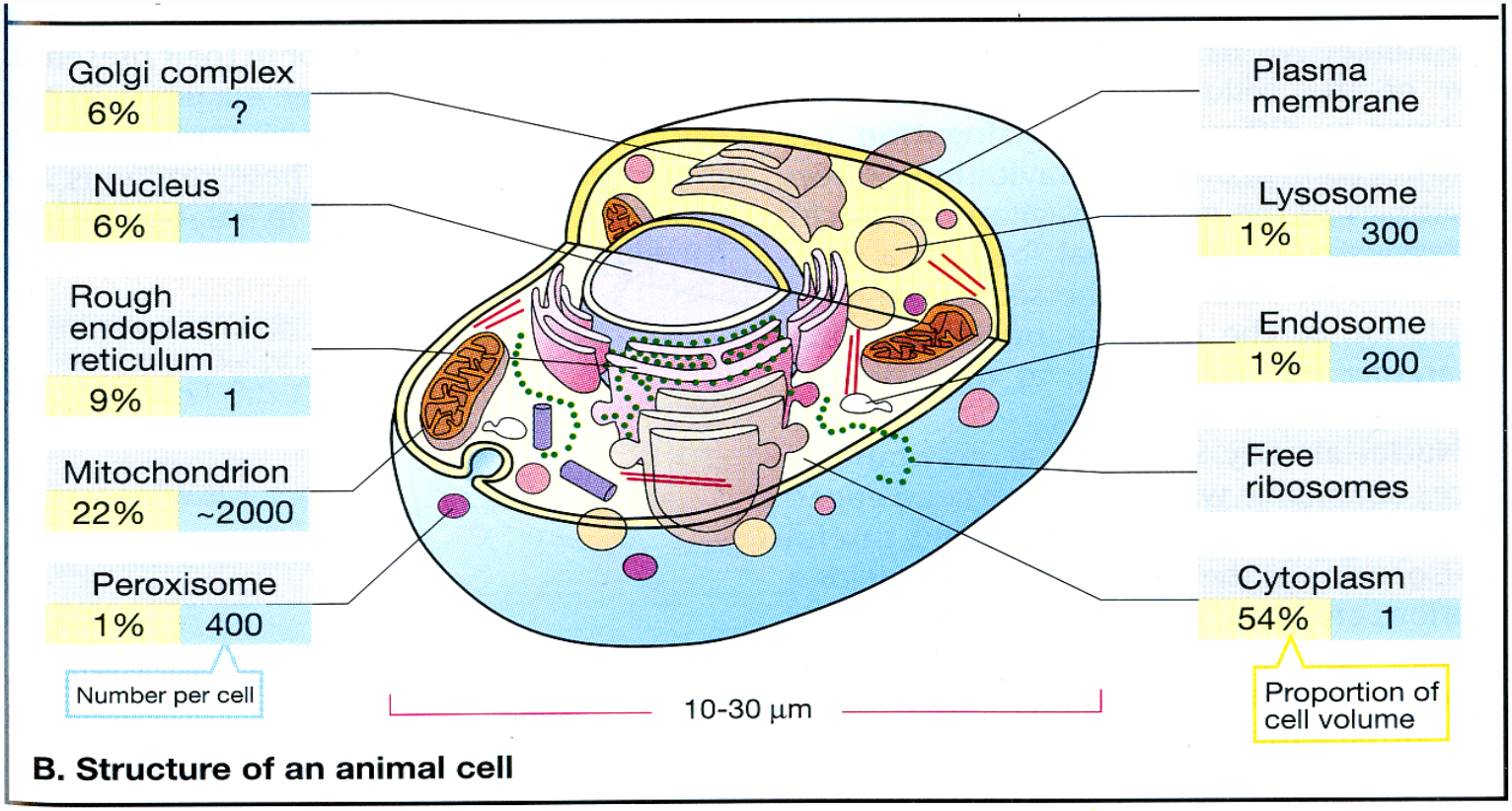
Biotechnology is major new growth area

Chemical Engineering can play an important role

The Role of Chemical Engineering In Biological Engineering

- All known life forms involve cells.
- A cell is the smallest self-preserving and self-reproducing unit.
- Many complex chemical reactions and complex transport processes occur
- A cell looks like a chemical plant
- Chemical engineers routinely work with that type of system.

Animal Cell: A Chemical Factory



B. Structure of an animal cell

How To Optimize Education To Take Advantage Of The Opportunity

- Biology becomes an integral part of the curriculum
- Enabling sciences go from the
- Traditional three legs

  Chemistry, Math, Physics

- To four legs

  Chemistry, Math, Physics, Biology

  (basic understanding of molecular and

  cellular biology)

Molecular and Cellular Biology

“Biology is complex chemistry that works”

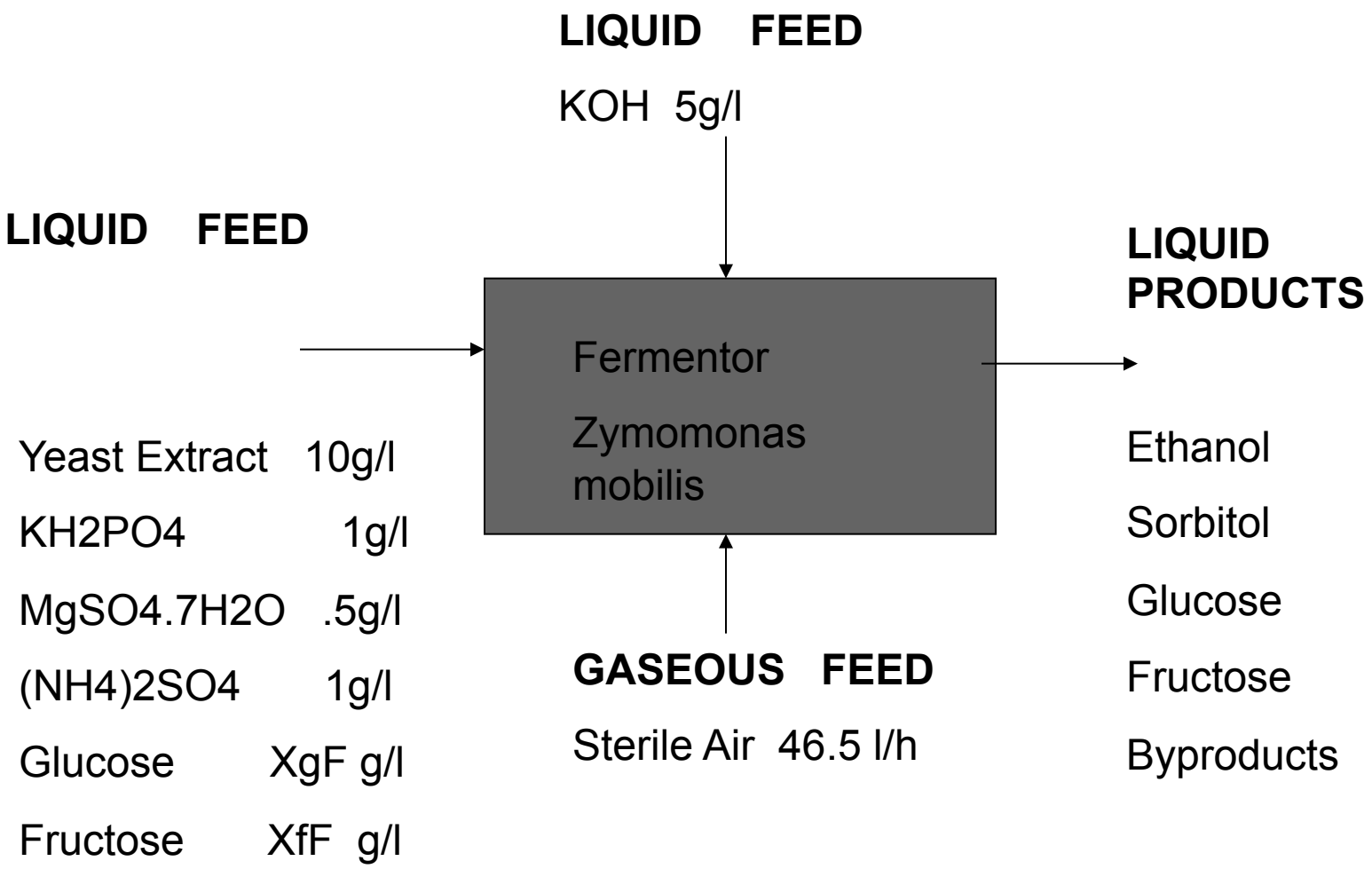
- Chemical engineers will not become biologists
- Must understand molecular biology and cell structures
- Molecular biology is insufficient to understand cell function
- Interaction of components defines the system.
- A systems approach is necessary

Welcome to chemical engineering

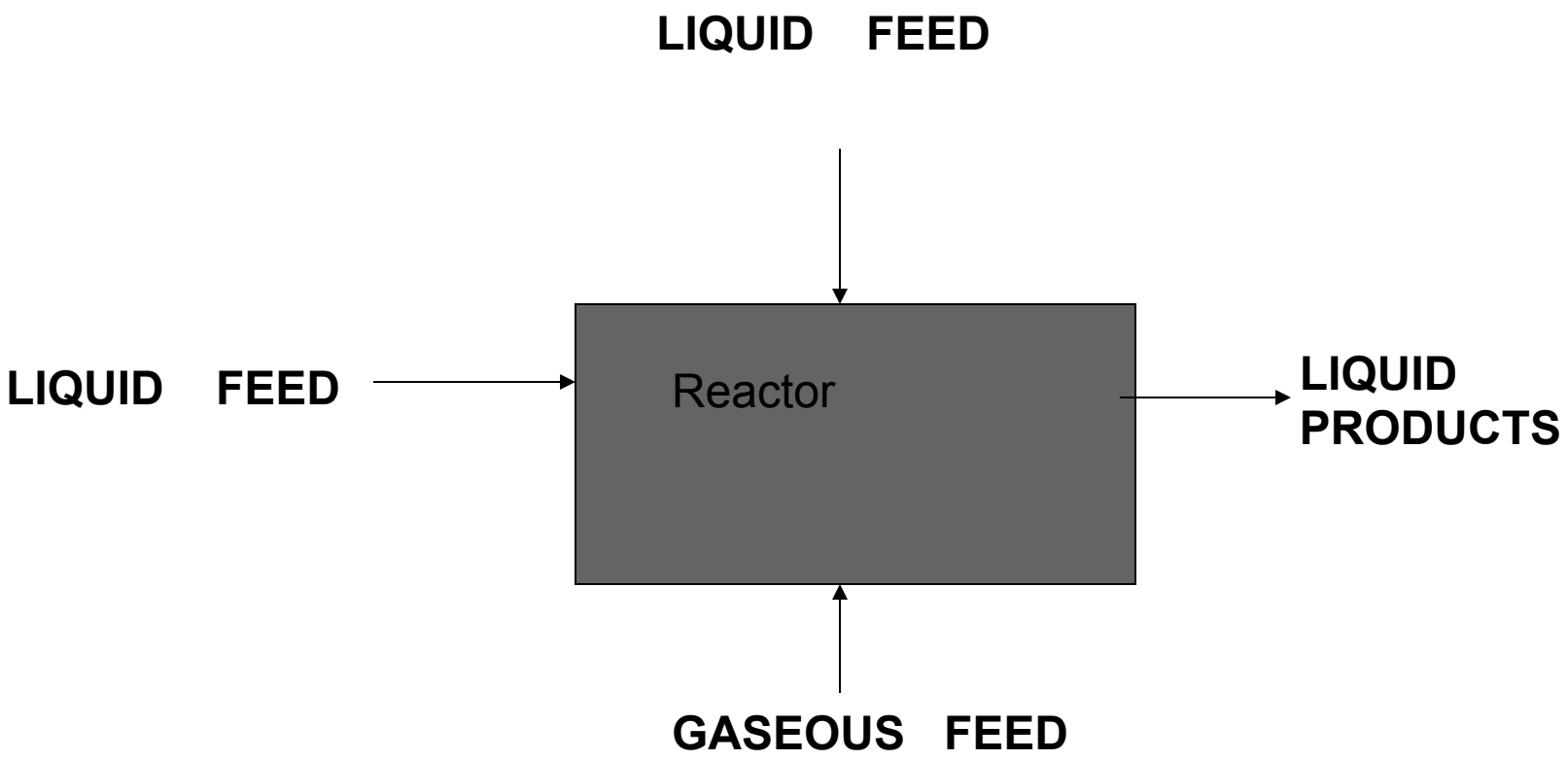
The “Patch” Approach

- Problems in courses inadequate
- Often disguise the real system problem by oversimplifying:
  - Kidney as simple separator
  - Body as pump and tubes
  - Liver as reactor
- Biological problems can be disconnected from the rest of the curriculum
- Neither approach adds to the solution of a real problem

Fermentor System as a Patch

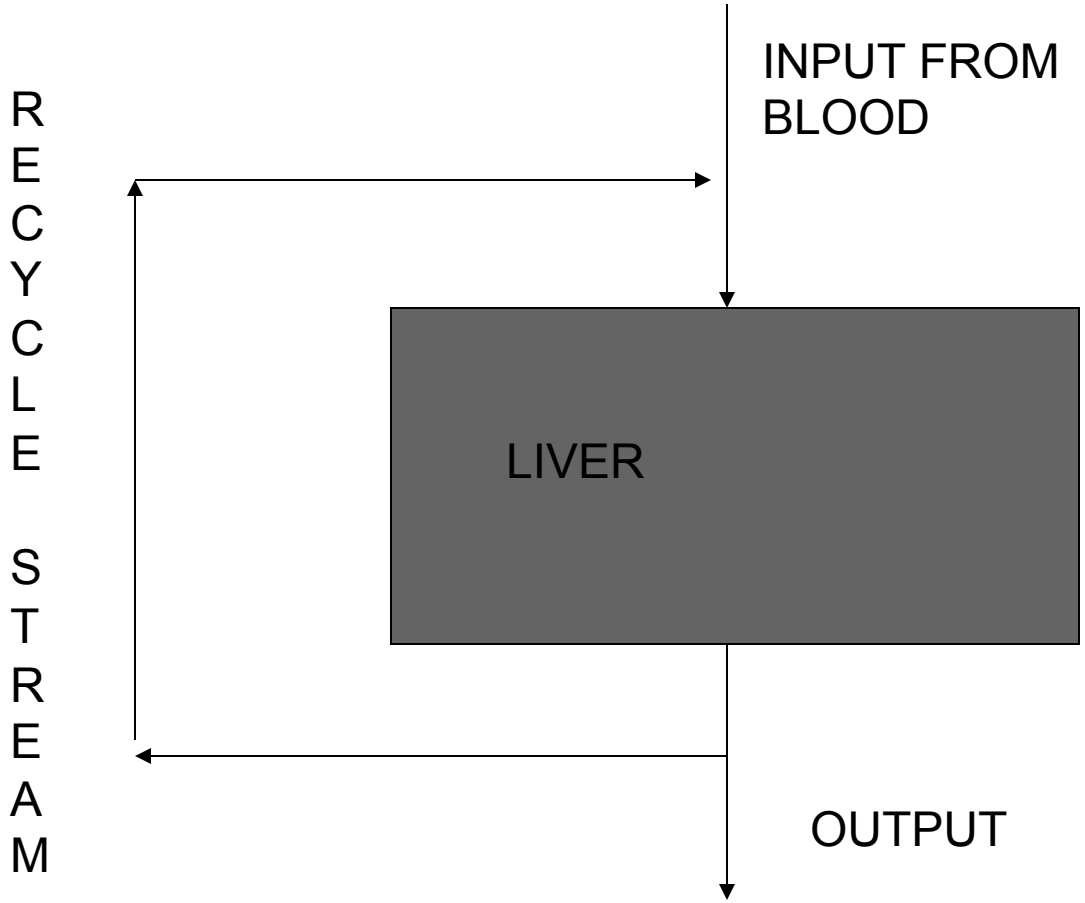


Fermentor Patch Example as a Generic System

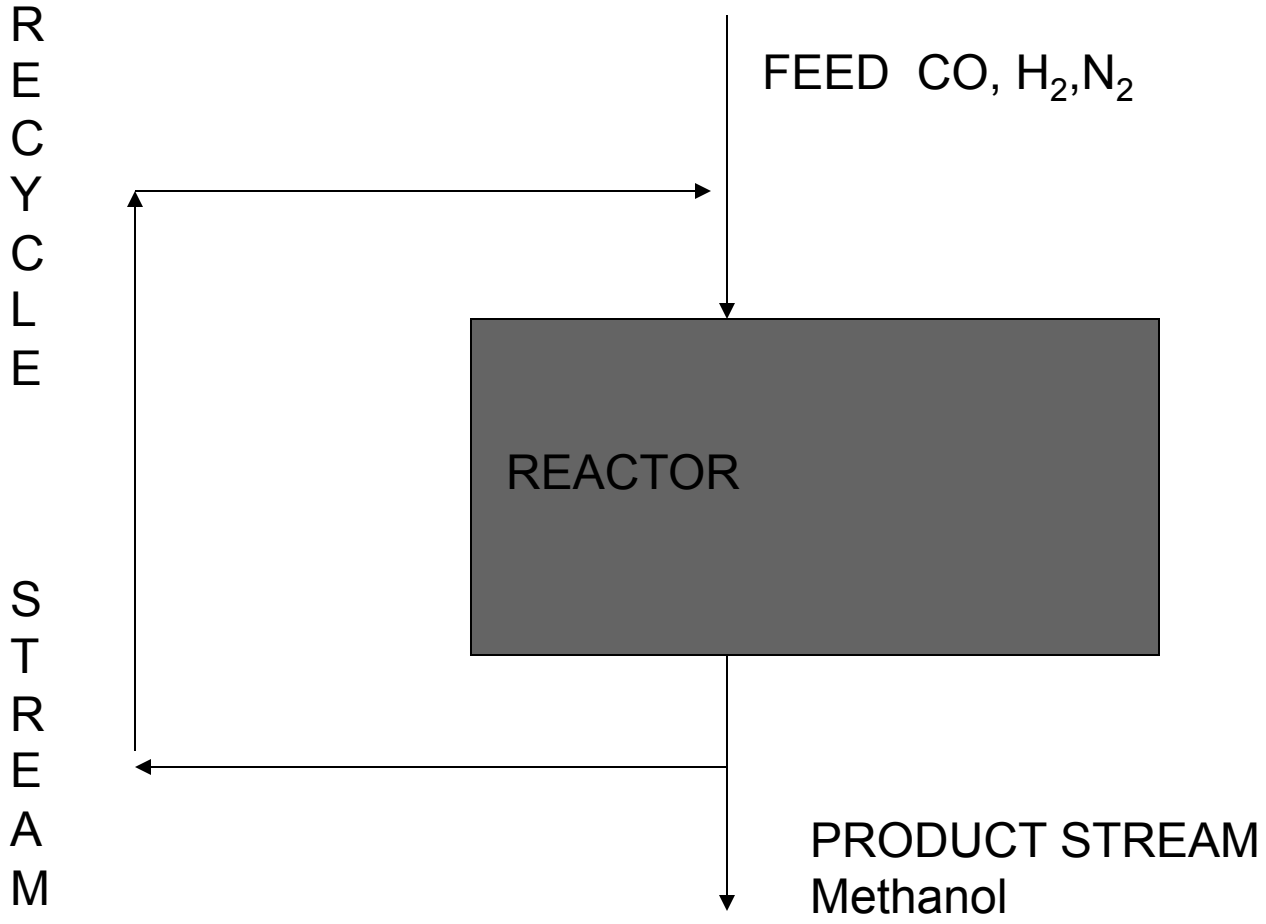


Another Patch Example
Recycling in the Liver

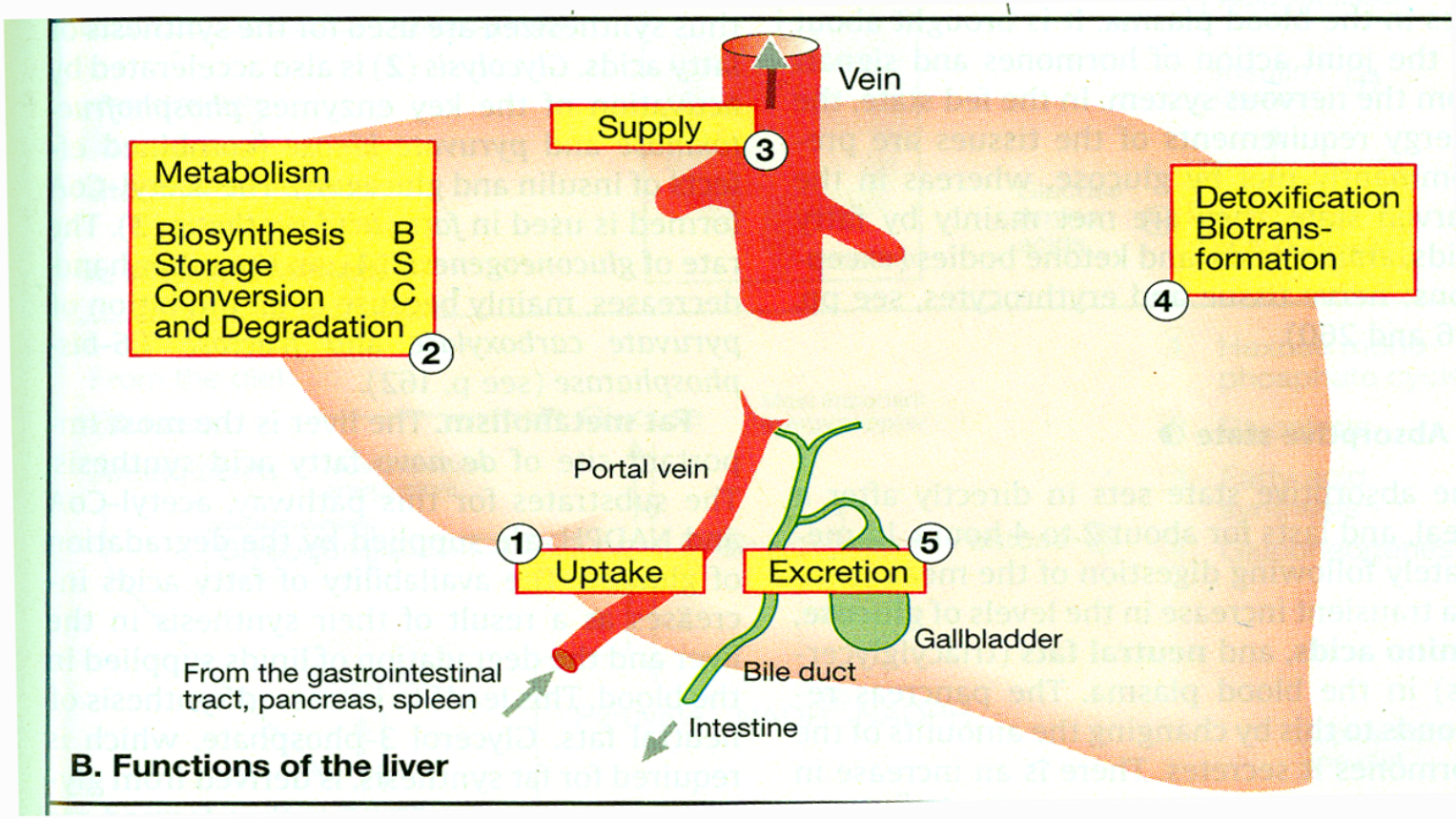
$CO_2 + 2NH_4^+$ = urea and byproducts



Simple Recycle With Reaction
Methanol Synthesis

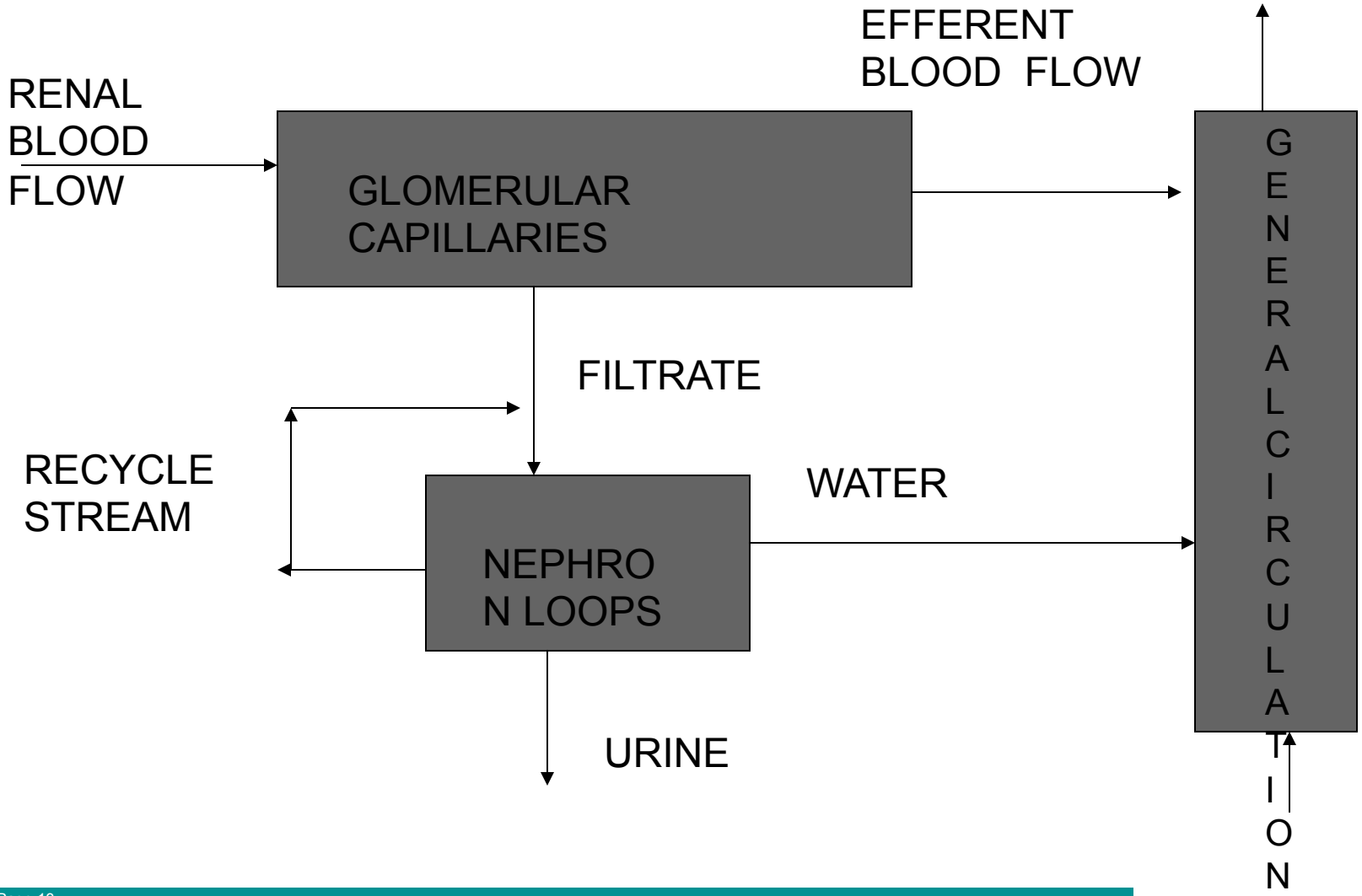


Liver Functions

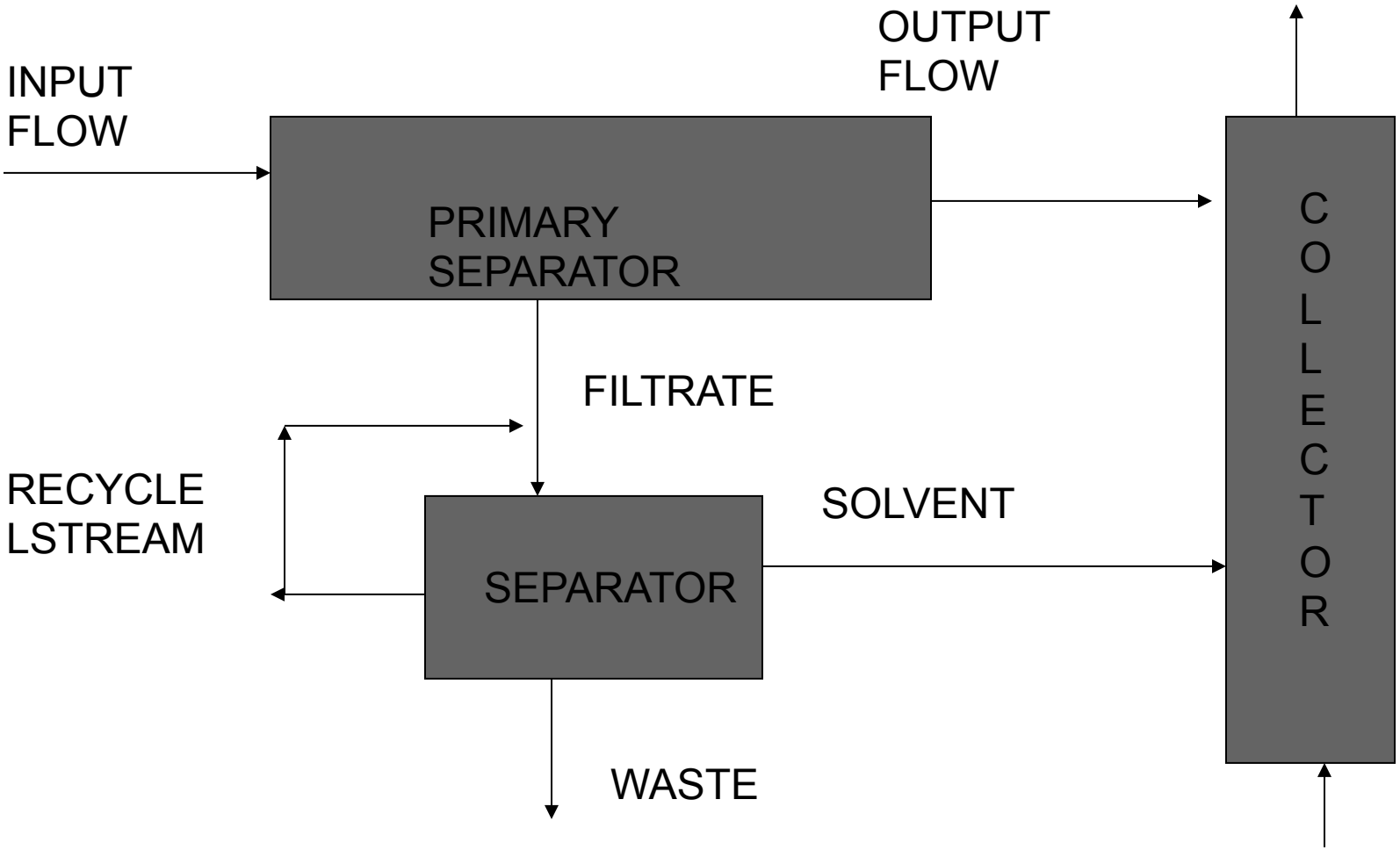


B. Functions of the liver

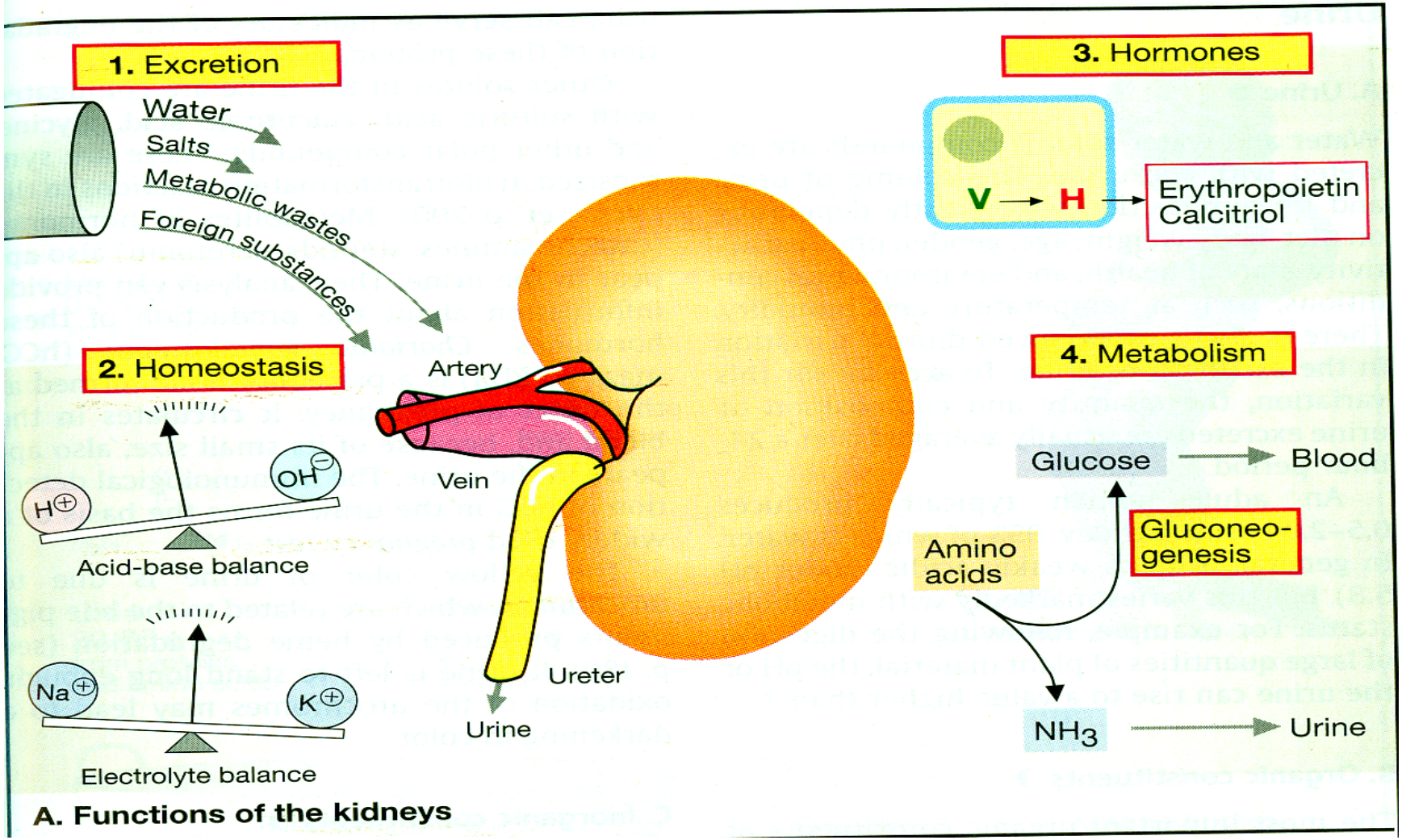
Urea Recycling in Kidney



Separation With Recycle

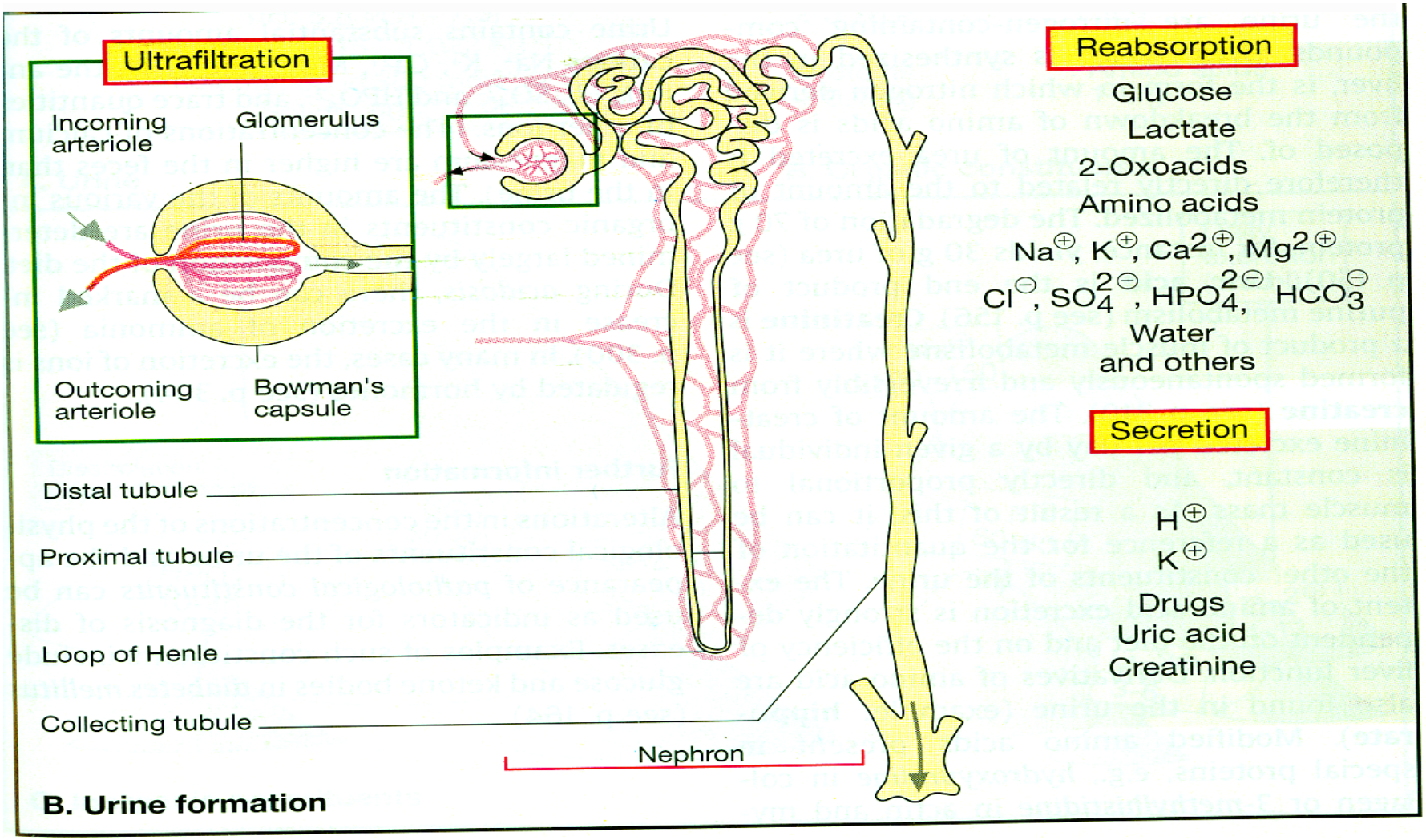


Kidney : Another Factory



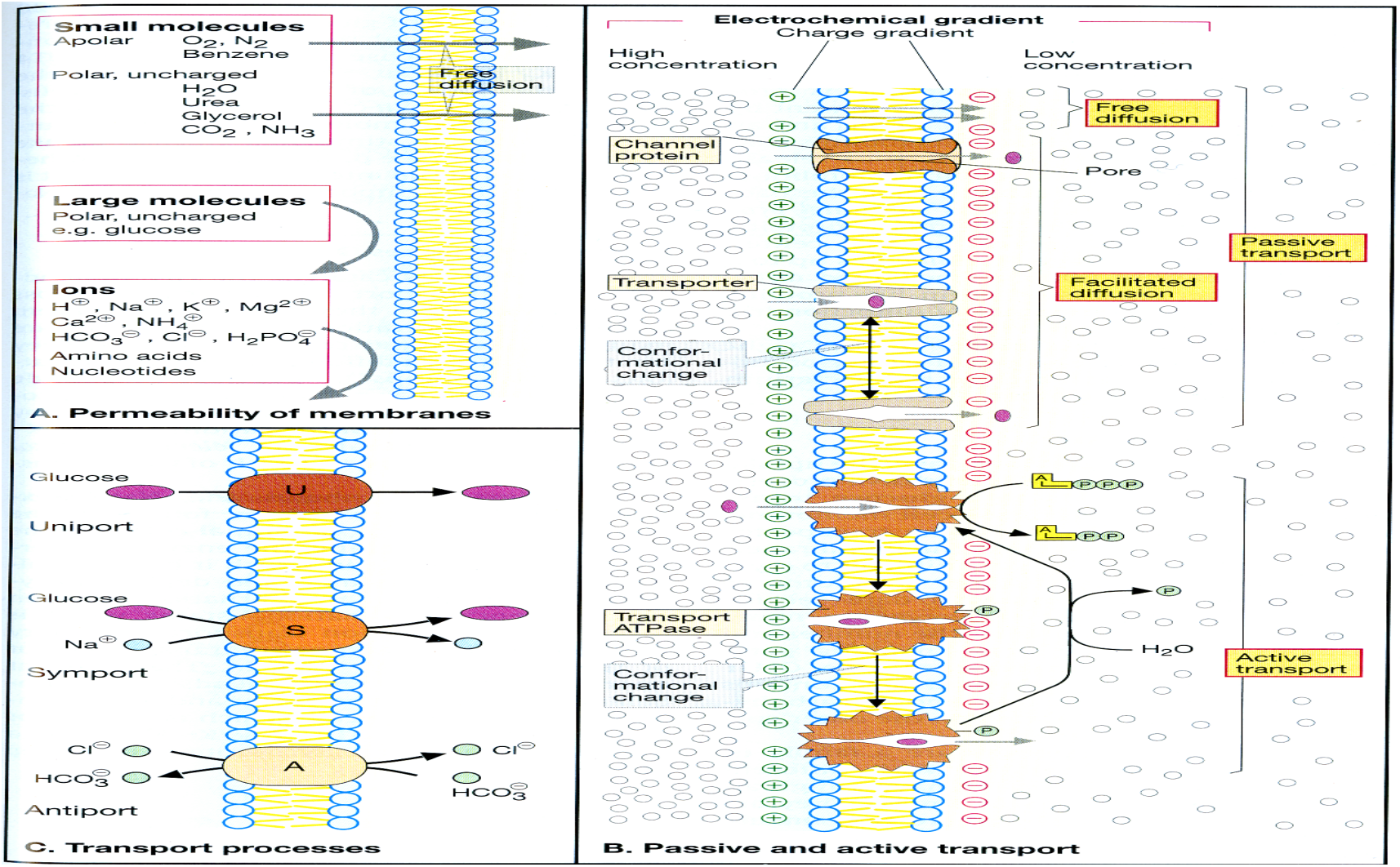
A. Functions of the kidneys

Urine Formation: Separation



B. Urine formation

Transport Processes



Appropriate approaches for Chemical Engineering

Ground rule:

•Since future “hot topics” are unknown, we do not want to destroy the traditional base as there is a fundamental intellectual core to the subject.

•The biological and biomedical engineering approach is too narrow as they are derivatives of the chemical engineering core

•Chemical engineers will not become molecular biologists but must understand it

The Seamless Approach

- A biological system is simply another system
- Usual approach to problem solving by chemical engineers is applicable
- Traditional approaches and material must be included
- Students must be able to function in a wide variety of technical situations involving chemistry and biology
- Students will work on both types of systems (biological and chemical) simultaneously in each core course
- Similarities as well as differences can be exposed.

The Thread

- Comparison between a biological system
  - cell, organ, organism and
  - traditional chemical plant (specialty, commodity) is examined in the first course.
- Choice of the chemical system can introduce new material (polymers, semiconductors). .
- Subsequent courses examine same systems with the detail appropriate to the new course material.
- The content of the entire curriculum is connected
- The overall program is brought into context.
- Issues of scale and complexity are introduced naturally

Chemical Process Calculations

To what extent can the behavior of a biological cell (as a chemical manufacturing plant) be described by a series of unit operations comparable to those considered in traditional chemical industry.

You are to describe a traditional chemical process in terms of relevant unit operations and do the same type of analysis for a biological cell.. Then, compare the two analyses.

What are similarities and dissimilarities? What do you need to know to carry out such an analysis? Include both material and energy balance considerations. What is the role of thermodynamics in this discussion?

Type of Cells

Prokaryotes: single-celled organisms without nucleus (e.g. bacteria)

1-10 microns,

very few cytoplasmic structures

Eukaryotes: organisms whose cells have membrane bound nuclei

that contain their genetic material, single cells to higher organisms

10-100 microns

highly structured (intercellular membranes, cytoskeleton)

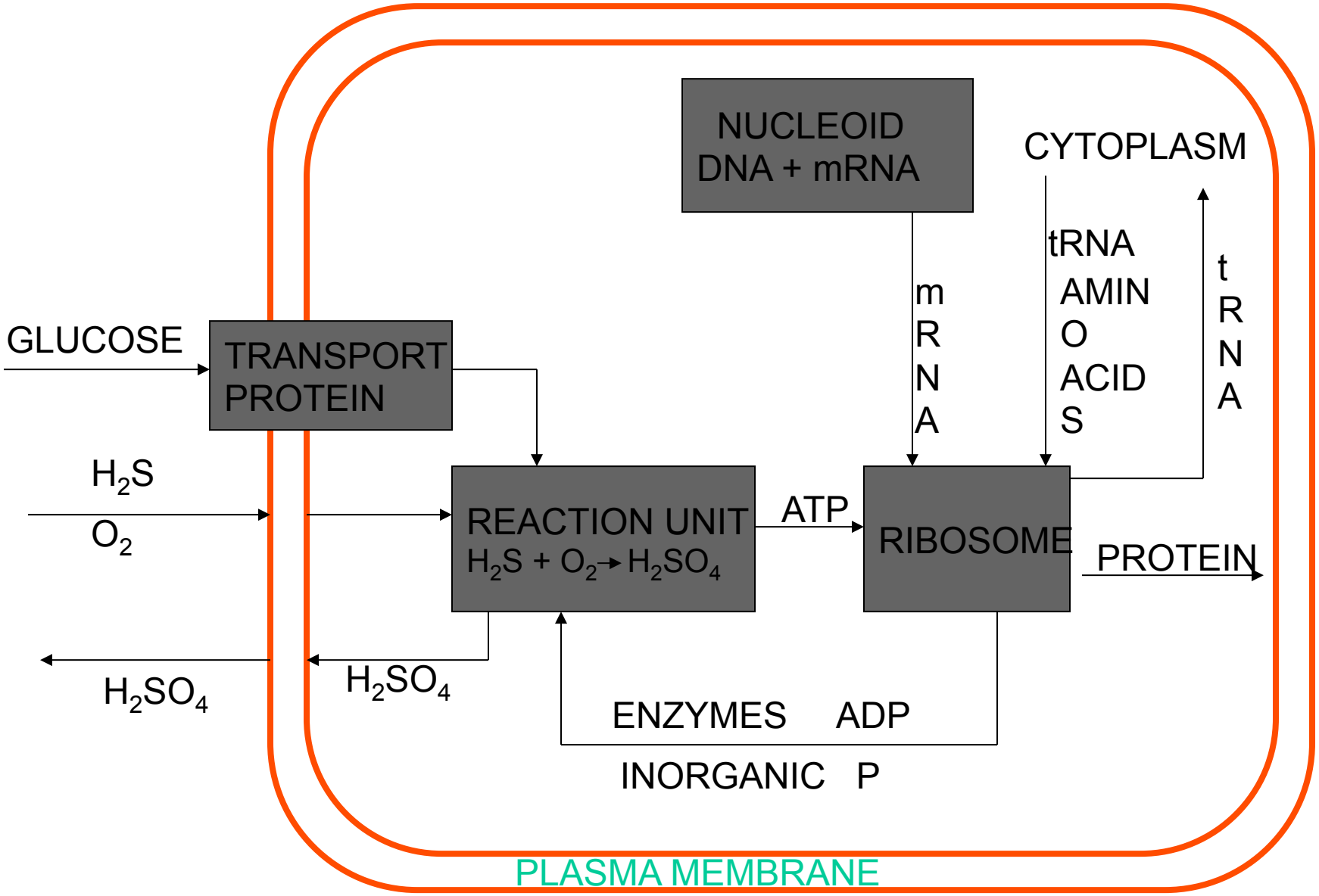
Archaea: prokaryotes often living in extreme environments

(geysers; alkaline, salty, or acid water)

Unusual biochemistry (CO_2 to CH_4; H_2S to H_2SO_4)

Biological Cell Type		Chemical Process
Archaea	→	Ammonia production
Prokaryote	→	Polyethylene
Eukaryote	→	Pennicillin
Archaea	→	Sulfuric Acid
Procaryote	→	Crude Oil to Gasoline
Eucaryote	→	Ethanol
Archaea	→	Bakers Yeast

A PROCESS ANALYSIS OF SULFURIC ACID PRODUCTION & ARCHAEAL CELLS



Sample Projects

Ethanol production

Biological: Zymomonas mobilis CP4

Chemical(macro): Continous fermentation of corn mash with the product stream processed

Ammonia Synthesis

Biological ADS positive bacteria

Chemical Haber process

Ammonia Clearance from Blood
The Reactor Analysis

- Free ammonium ion (NH_4^+) is toxic at high concentrations
- In the body, the liver removes NH_4^+ by forming urea ($CO(NH_2)_2$); this process is not an elementary reaction; it involves multiple enzyme-catalyzed steps.
- Net stoichiometry:

$$2NH_3 + CO_2 \rightarrow urea$$

Rate Law

Simplified power-law approximation (assumes CO_2 is in excess):

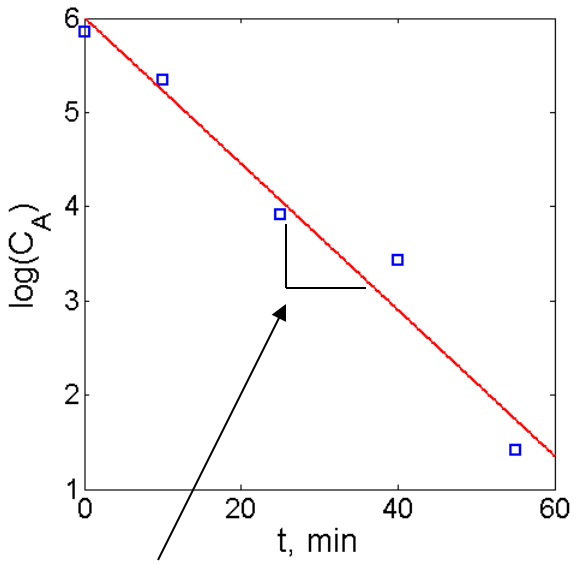
$$-r_A = \frac{dC_A}{dt} \cong k_a C_A^{\ n} \qquad A: Ammonia$$

Reaction Order Estimate from Batch Data

Culture conditions: 10×10^6 cells/mL, 1 mL culture volume

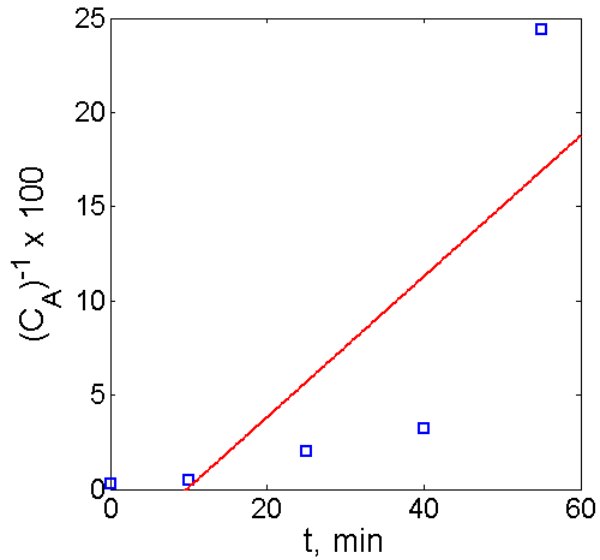
t, min	C_A, μM
0	350
10	210
25	50
40	31
55	4

n = 1



k_a = 0.08 min^{-1}

n = 2



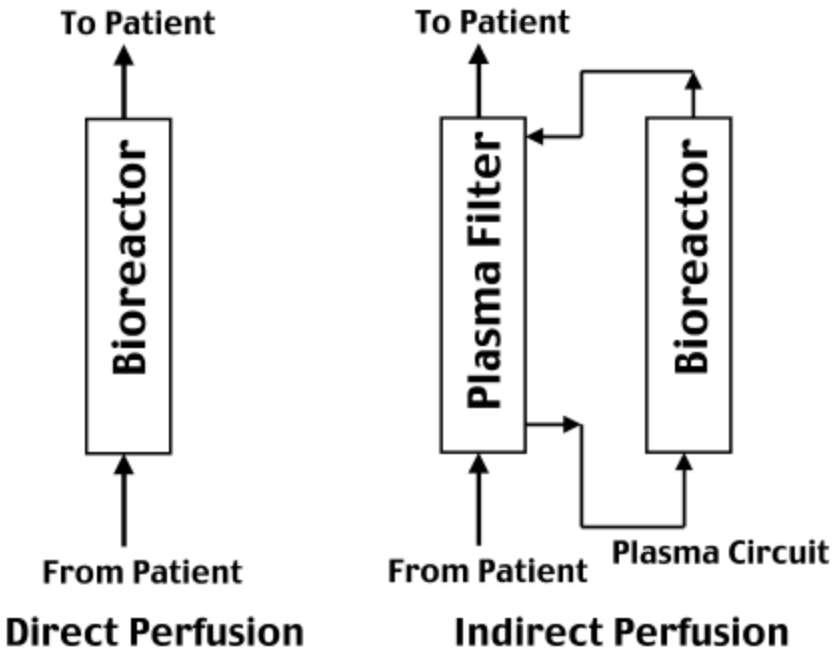
Max rate: $k_a C_{A0} = 28\,\frac{\text{umol}}{\text{L}\cdot\text{min}}\left(\frac{10^{-3}\,\text{L}}{10^7\,\text{cells}}\right)\left(\frac{60\,\text{min}}{1\,\text{hr}}\right) = 0.17\,\frac{\text{umol}}{10^6\,\text{cells}\cdot\text{hr}}$

Cell Mass Requirement

Elimination of nitrogen through urine in average adult: 10 g/day

- NH_3 elimination: 12 g/day (assuming 100 % association with urea)

Possible liver bioreactor perfusion configurations:



Are there any limitations on bioreactor size and density (cell-to-volume ratio)?

Real Life Examples: Robert Langer, MIT

Most Famous and Successful Chemical Engineer

Controlled Release, Tissue Engineering, Medicine and Biotechnology
http://en.wikipedia.org/wiki/Robert_S._Langer

Real Life Examples: RA Mashelkar

Most Famous and Successful Indian/ICT Chemical Engineer

Hydrogels, Anticancer drugs, IPR, Traditional drugs
http://en.wikipedia.org/wiki/Raghunath_Anant_Mashelkar

Real Life Example: K Vijayraghvan

Chemical Engineer: IIT Kanpur

Molecular Biology, Cell Biology
http://en.wikipedia.org/wiki/K._VijayRaghavan

Real Life Example: Samir Mitragotri

ICT Chemical Engineer, Professor, UCSB
Drug Delivery, Biotechnology, Transdermal patch

http://en.wikipedia.org/wiki/Samir_Mitragotri

Industries

Reliance Life Sciences
Intas
Biocon
USV
Cipla

Pfizer
Merck
Sanofi
Roche
GSK

Wish you acedemic success!