EngrD 2190 – Lecture 6

Concept: Process Design Evolution by Incremental Improvement

Context: Example Exercises with Approximate Flow Rates
(exercises 2.36 and 3.126 – solutions are posted)

Read Chapter 3 pp. 89-99 (mass balances)
and Appendix C (significant figures).

Lecture 7 will follow the textbook. Bring pages 95-99
to Lecture 7. Take notes by annotating in color.

Active Learning Initiative Research Opportunity

- Cornell CBE is implementing active learning into the core ChemE curriculum.
- We seek your perspectives on learning, careers, and more! **We have sent a ~15-minute survey to your email** with the subject "Cornell CBE Active Learning Initiative Research Study Invitation"
- After you complete the survey, you will be contacted with the opportunity to participate in an interview at the end of this semester and receive a **$25 gift card as compensation**. Please **complete the survey by 12/1/2025** to be eligible for this incentive.
- Please email Francis at fl297@cornell.edu with any questions. Thank you for your support!

STRIDE

CornellEngineering
Smith School of Chemical and Biomolecular Engineering

Writing Your Experience as Accomplishment Statements

- Your experience on a resume should not be a list of activities.
  - They should b[illegible] Deductive [illegible]hments.
- Experience writte[illegible] statements describe what **<u>impact your work had</u>** on the organization.
  - How were things improved through your work?
- Whenever possible, **<u>use metrics</u>** to describe your impact on the organization.

Example

Writing Accomplishment Statements

Average	Better!
Responsible for health promotion efforts.	Organized a company sponsored walk-a-thon which raised over $8,000 for the American Heart Association and involved [illegible] f over 200 employees.
Handled bookkeeping for [illegible] store.	[illegible] erred vendors and [illegible] approval process for purchasing that reduced incidental expenses by 35%.
Performed filing and other clerical duties.	Re-organized and maintained over 350 technical files, thereby reducing the file search time by an average of three hours weekly.
Responded to customer inquiries and problems.	Earned the corporation's annual "Outstanding Service Provide" award based on feedback from both internal and external customers.

Inductive

Quick gut check: At the end of each statement on a resume, ask 'so what?'

Examples in Process Design

Design Evolution
by Incremental Improvements

Solutions are posted

Exercise 2.36

2.36 A good product G is produced by the following reaction:

$$M + E \rightarrow 2G \qquad \text{rxn 1}$$

Reactants available: a liquid mixture of M (50 mol%) and X (50 mol%)
a liquid mixture of E (50 mol%) and I (50 mol%)

Compound I is inert. In a mixture of M, X, E, and I, a side reaction produces by-product B:

$$X + E \rightarrow 2B \qquad \text{rxn 2}$$

Reactions 1 and 2 are highly exothermic. A mixture of 50 mol% M and 50 mol% E will explode. Likewise for X and E. To avoid explosion, E must not exceed 1 mol% if M and/or X are present.

All reactants and products are soluble in water. Water is inert to all reactants and products.

Complication: Cannot separate E and I.

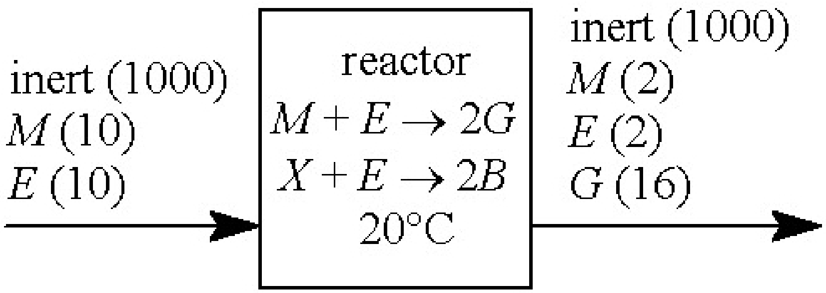
Exercise 2.36 – Reaction Details

Reactions 1 and 2 do not go to completion at the safe reaction temperature, 20°C. That is, if M and E enter a reactor, the amounts leaving the reactor will be such that

$$\frac{(\text{mol } G)^2}{(\text{mol } M)(\text{mol } E)} = 60$$

Deductive

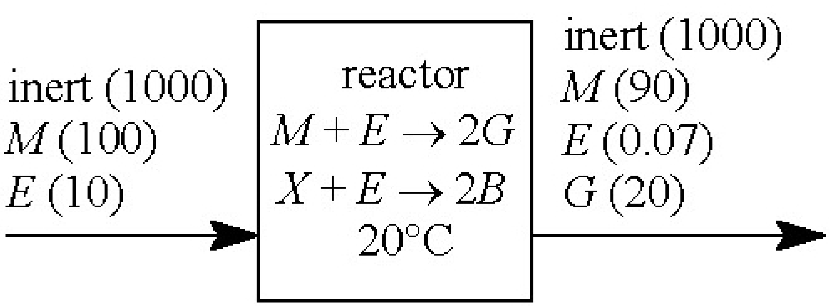
Two examples of reactor effluents are shown below. The first uses a stoichiometric mixture of M and E. The numbers in parentheses are flow rates, in mol/min.



$$\frac{16^2}{(2)(2)} = 64 \approx 60$$

Inductive

The second example shows a result when M is in excess.



$$\frac{20^2}{(90)(0.07)} = 63 \approx 60$$

Likewise if X and E enter a reactor, the concentrations leaving the reactor will be such that

$$\frac{(\text{mol } B)^2}{(\text{mol } X)(\text{mol } E)} = 60$$

Exercise 2.36 – Goals and Rules

Design Goals (in decreasing importance):

- Maximize the yield of product G and any other marketable by-product(s).
- Minimize the yield of flow rate of the mixture of M and X.
- Minimize the number of units in your process.

Design Rules:

- Use 20 mol/min of the mixture of E (50 mol%) and I (50 mol%). You may use as much of the mixture of M (50 mol%) and X (50 mol%) as you wish.
- Indicate *approximate* flow rates of the substances in each stream. One significant figure is sufficient.

Exercise 2.36 – Two Hints

Hint: In this exercise, the total number of mols is constant in both reactions. If a total of 20 mols of M and E enter a reactor, then a total of 20 mols of M, E and G will leave the reactor. (Note - this is *not* a general principle.) Also, if a total of 100 mols of M, E, X, and I enter your process, then a total of 100 mols of M, E, X, I, B, and G must leave your process. Because I is inert, if 10 mol of I enter your process, then 10 mol of I must leave your process.

To calculate the flow rates of M, E, and G in the reactor effluent, assume x mols of M and E react to form $2x$ mols of G. For example, if 10 mol M and 10 mol E enter the reactor -

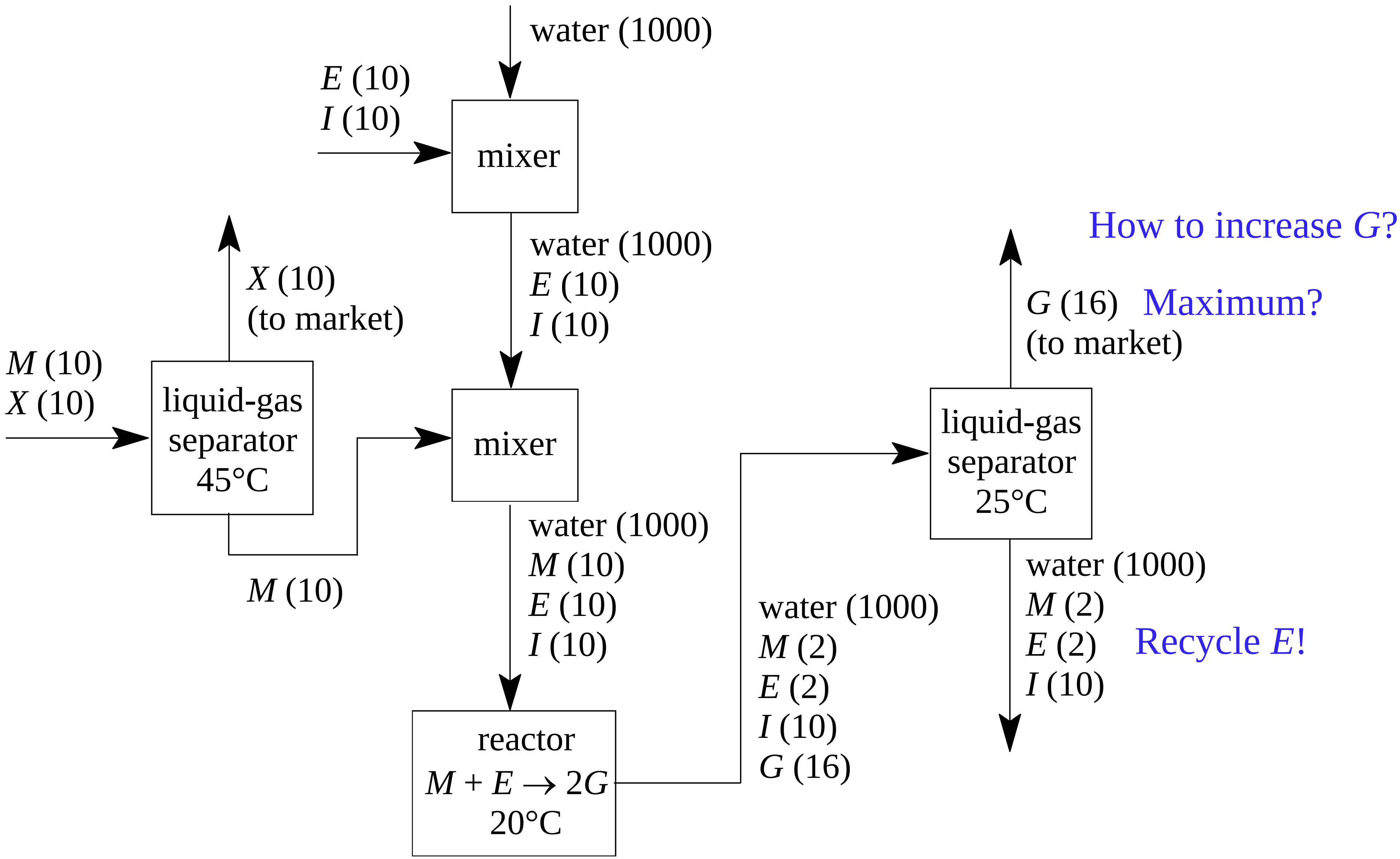
$$\frac{(\text{mol } G)^2}{(\text{mol } M)(\text{mol } E)} = 60$$

$$\frac{(2x)^2}{(10-x)(10-x)} = 60$$

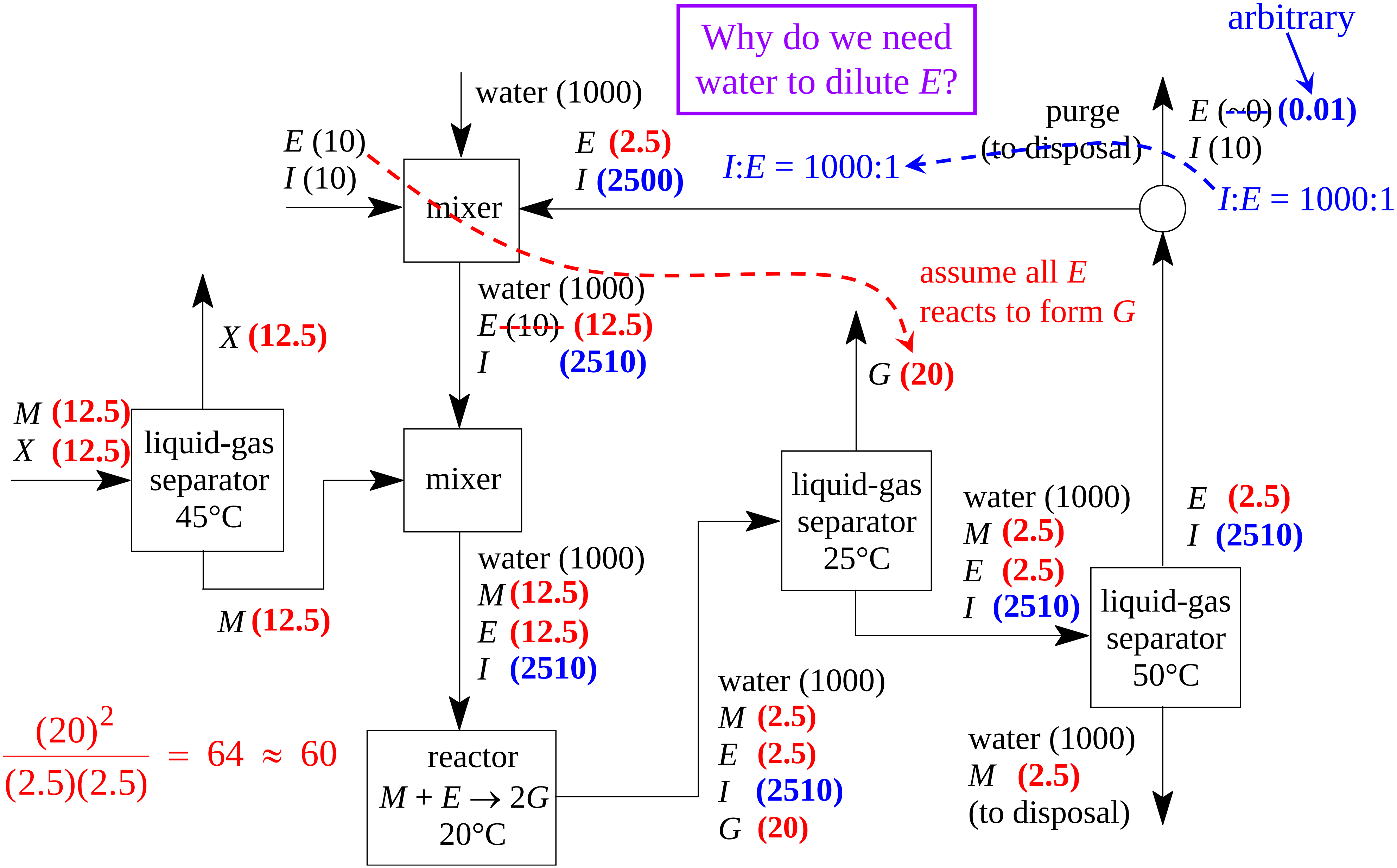
$$x \approx 8$$

Thus 2 (= $10 - x$) mol M, 2 (= $10 - x$) mol E, and 16 (= $2x$) mol G leave the reactor.

First attempt: Separate *X* from *M*, dilute *E* in water.



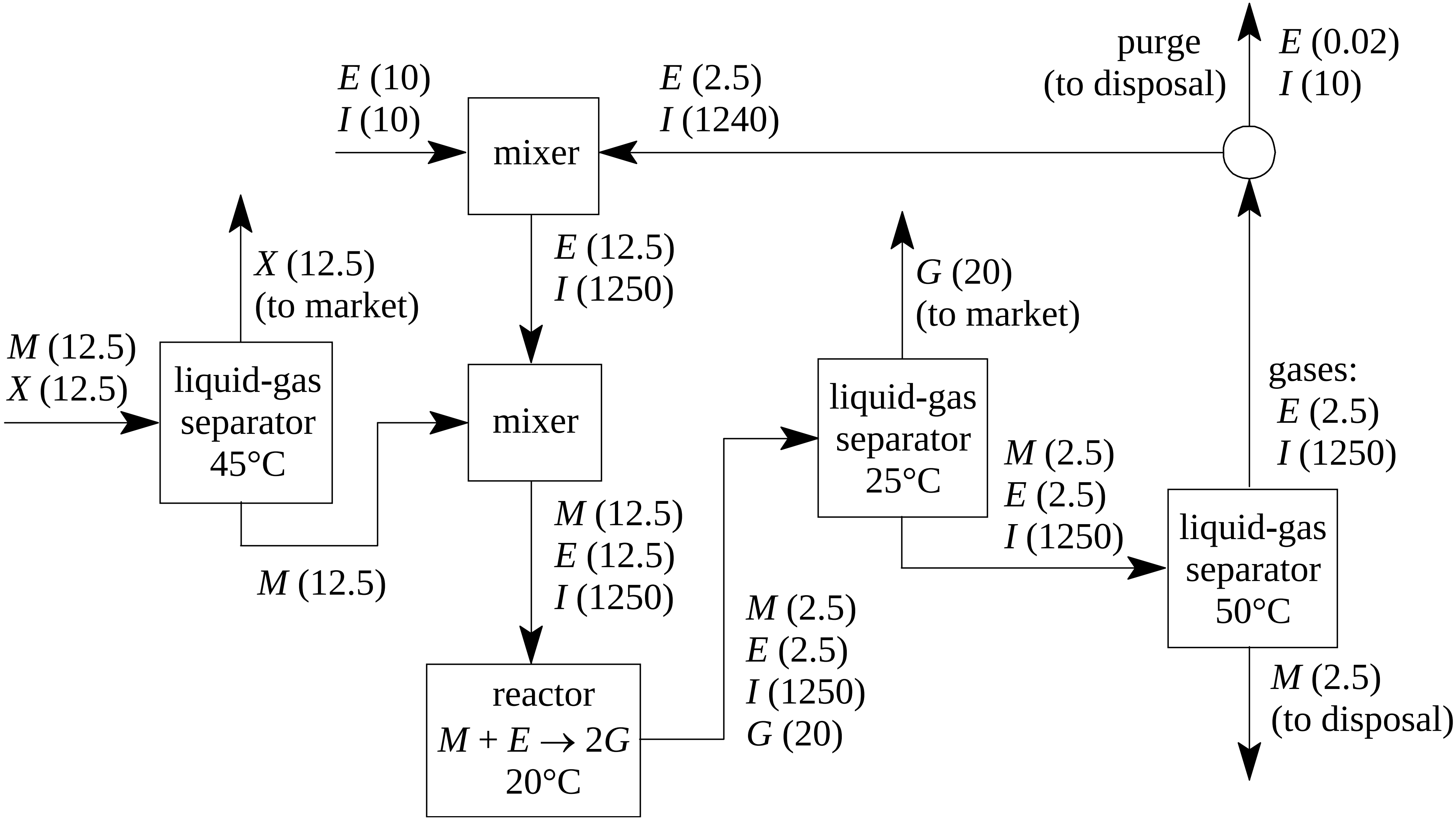
First attempt: Separate *X* from *M*, dilute *E* in water, recycle *E*.



$$\frac{(20)^2}{(2.5)(2.5)} = 64 \approx 60$$

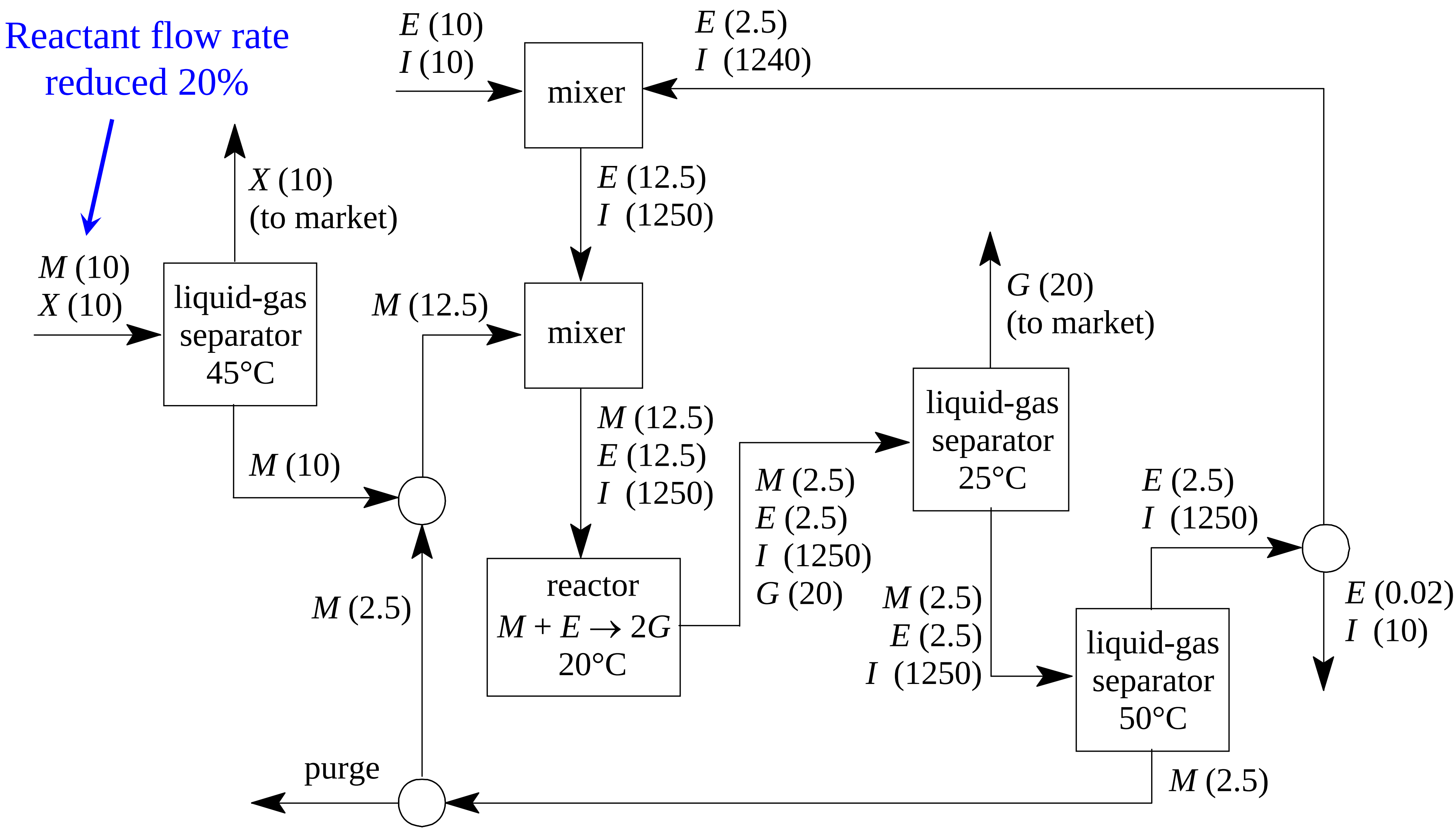
Purge a stream with a high concentration of impurity to minimize loss of desired substance(s).

2nd evolution: Use inert *I* to dilute *E*.

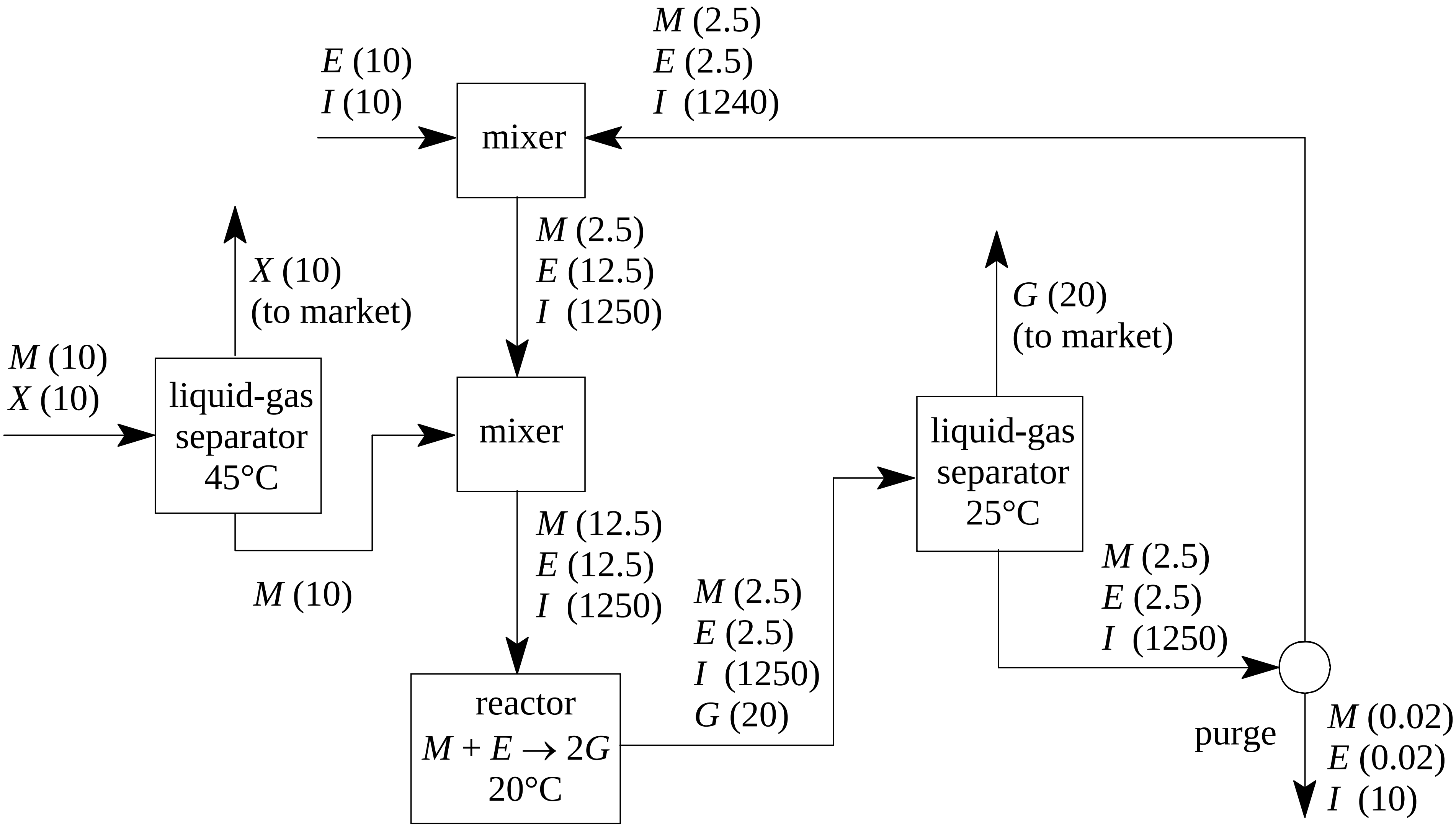


Waste treatment reduced
to 2.5 mol/min
from 1000 mol/min.

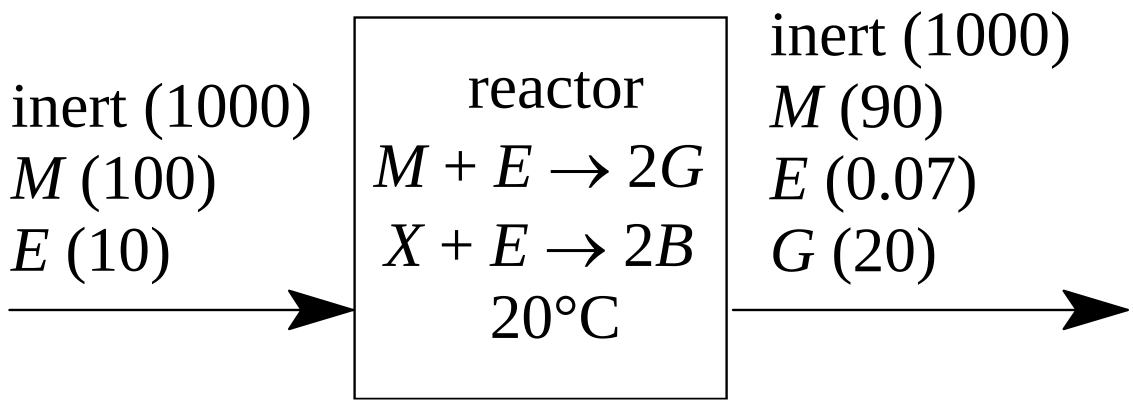
3rd evolution: Use inert *I* to dilute *E*, recycle *M*.



4th evolution: Recycle *E* and *M* without distillation.



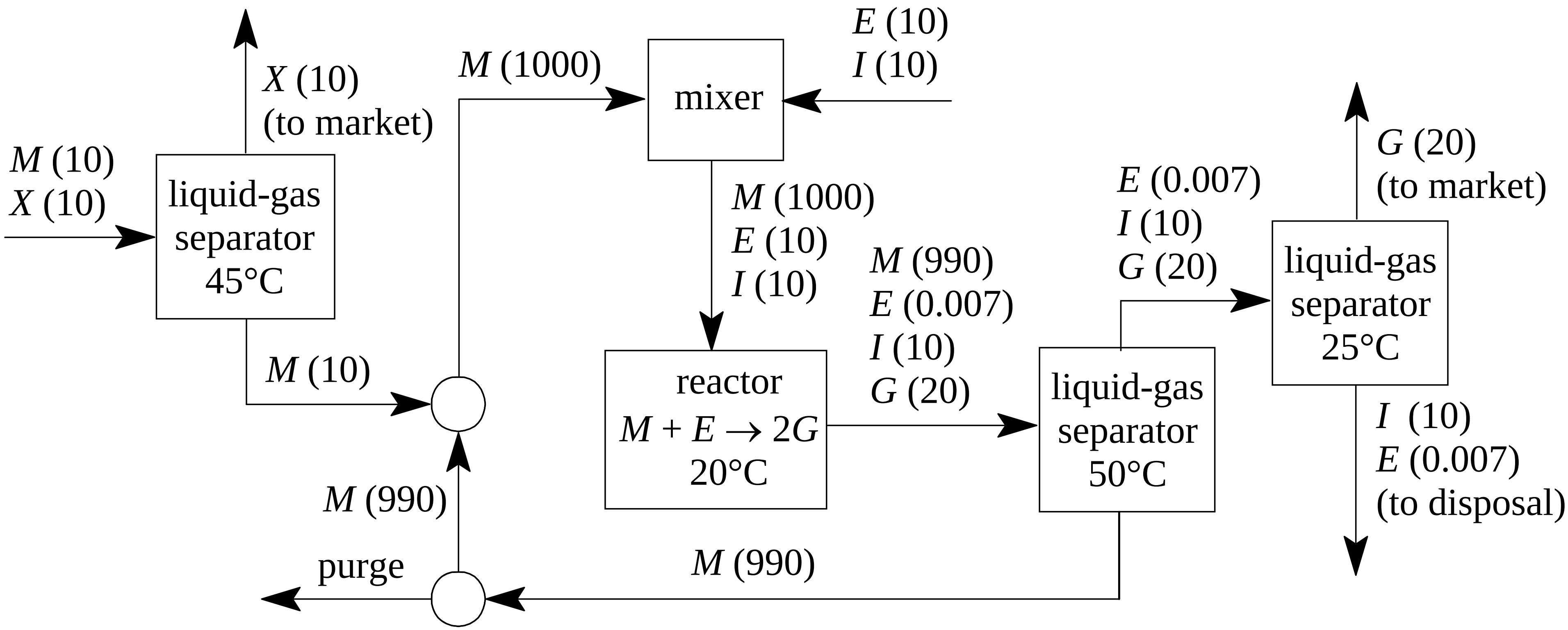
Next evolution hinted by the second example of reactor flow rates.



Excess reactant M can serve as the ‘inert’ solvent!

The amount of E in the reactor effluent
(and thus the amount of E purged)
can be decreased by excess M in the reactor!

5th evolution: Use M to dilute E.



Elegant!

Exercise 2.36: Lessons Learned

Accumulate inert substances in a recycle loop to decrease ancillary losses in a purge stream.

When choosing a solvent, consider the requirements for the solvent. In this example, water is viable, but inert *I* is better, and reactant *M* is better yet.

Start with a simple design and evolve by identifying the *real* problem.

Example Exercise from Prelim 1, 2014.

3.126 Design a process to obtain pure A from a mixture of A, B, and I; A:B:I = 11 mols:2 mols:1 mol. Because A, B, and I have the same melting point and the same boiling point, the mixture cannot be separated by physical means.

But A, B, and I have different chemical reactivities. I is inert; I reacts with nothing.

A and B react to form K.

$$A + B \overset{\text{catalyst 1}}{\leftrightarrow} 2K$$

Reaction is at 200°C and requires the presence of catalyst 1.

Reaction is reversible and $\dfrac{(\text{mol } K)^2}{(\text{mol } A)(\text{mol } B)} \approx 1$ in the reactor effluent.

K reacts *irreversibly* with Z to produce M and release B.

$$2K + Z \overset{\text{catalyst 2}}{\rightarrow} 2M + B$$

Reaction is at 100°C and requires the presence of catalyst 2.

For $\dfrac{\text{mol } Z}{\text{mol } K} > 10$ in the reactor input, all K is consumed.

For $\dfrac{\text{mol } K}{\text{mol } Z} > 10$ in the reactor input, all Z is consumed.

Finally, M decomposes reversibly to A and Z.

$$2M \overset{\text{catalyst 1}}{\leftrightarrow} A + Z$$

Reaction is at 200°C and requires the presence of catalyst 1.

Reaction is reversible and $\dfrac{(\text{mol } M)^2}{(\text{mol } A)(\text{mol } Z)} \approx 1$ in the reactor effluent.

Exercise 3.126 reactions

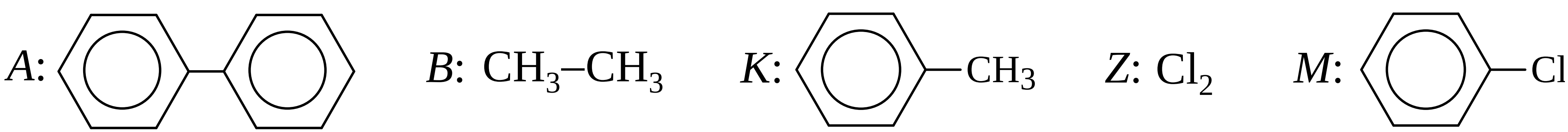
$$A + B \leftrightarrow 2K$$

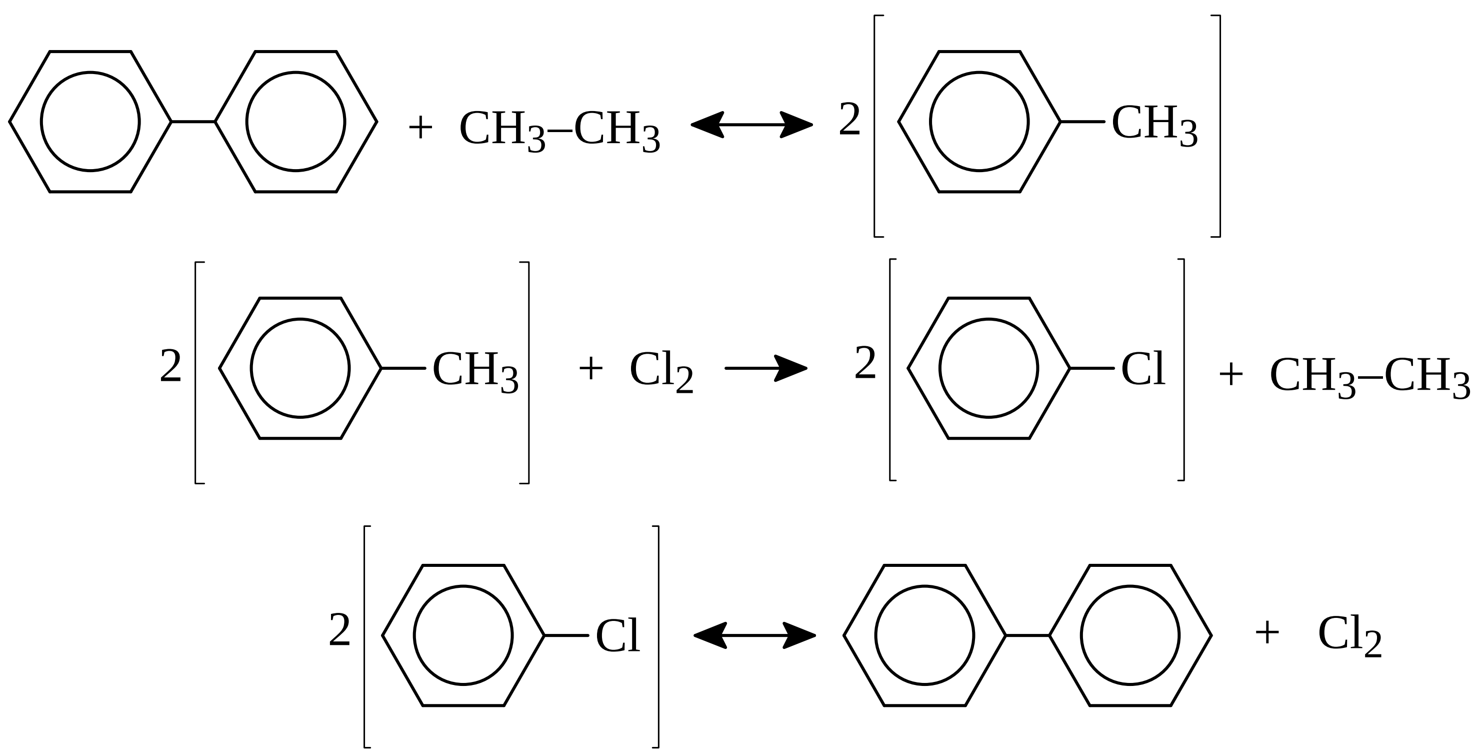
$$2K + Z \rightarrow 2M + B$$

$$2M \leftrightarrow A + Z$$

Deductive

Here are some possible chemical components represented by *A*, *B*, *K*, *M* and *Z*, but wrong melting points, boiling points, and chemical reactions:





Inductive

Exercise 3.126 – Goals and Rules

Design Goals (in decreasing importance)

Maximize the output of pure *A*. You must produce at least 10 mol/min of pure *A* for full credit.

Minimize the input of *Z*.

Minimize the *number* of units.

Design Rules

Use 14 mol/min of the *A*+*B*+*I* mixture: 11 mol *A* + 2 mol *B* + 1 mol *I*.

You may use as much *Z* as you wish.

Use only one catalyst per reactor. The catalyst is a permanent part of a reactor. You need not add catalyst and there is no catalyst in the reactor output.

Liquid-solid separators produce wet solids.

Exercise 3.126: Strategy to Maximize A

Convert $A + B$ to K: $A + B \leftrightarrow 2K$

Separate K from A, B, and I.

React K with Z: $2K + Z \rightarrow 2M + B$

Separate M from B and excess Z.

Recycle B to first reactor.

Convert M to $A + Z$: $2M \leftrightarrow A + Z$

Separate pure A from M and Z. **Product!**

Recycle M and Z to separator in 2nd step.

Exercise 3.126: Alternate Strategy

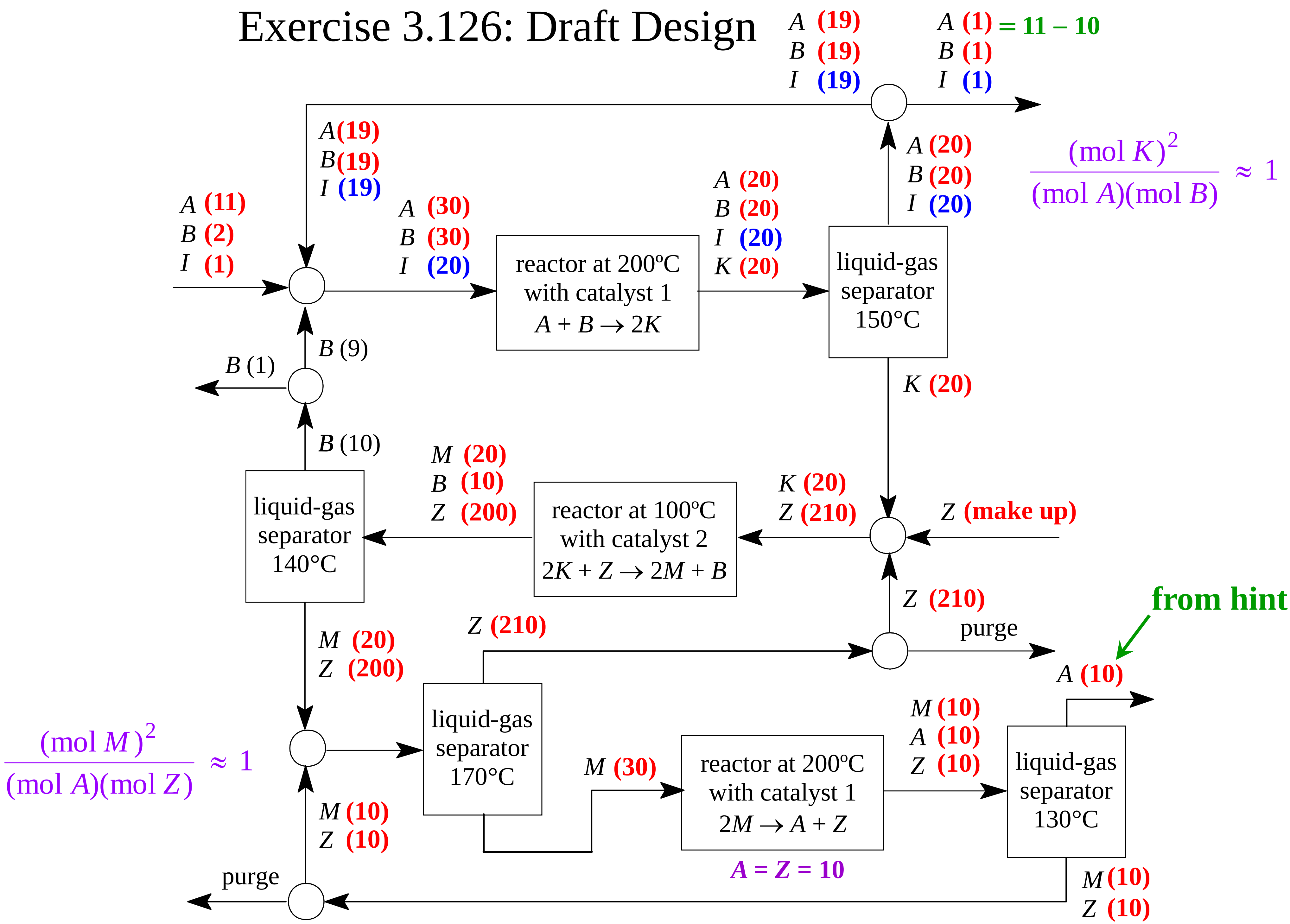
Work backwards from the product.

If we had pure M, we could convert M to $A + Z$.
Separate pure A from M and Z. **Product!**

React K with Z to form M (and B): $2K + Z \rightarrow 2M + B$
Separate M from B and excess Z.

React $A + B$ to form K: $A + B \leftrightarrow K$
Separate K from A, B, and I.

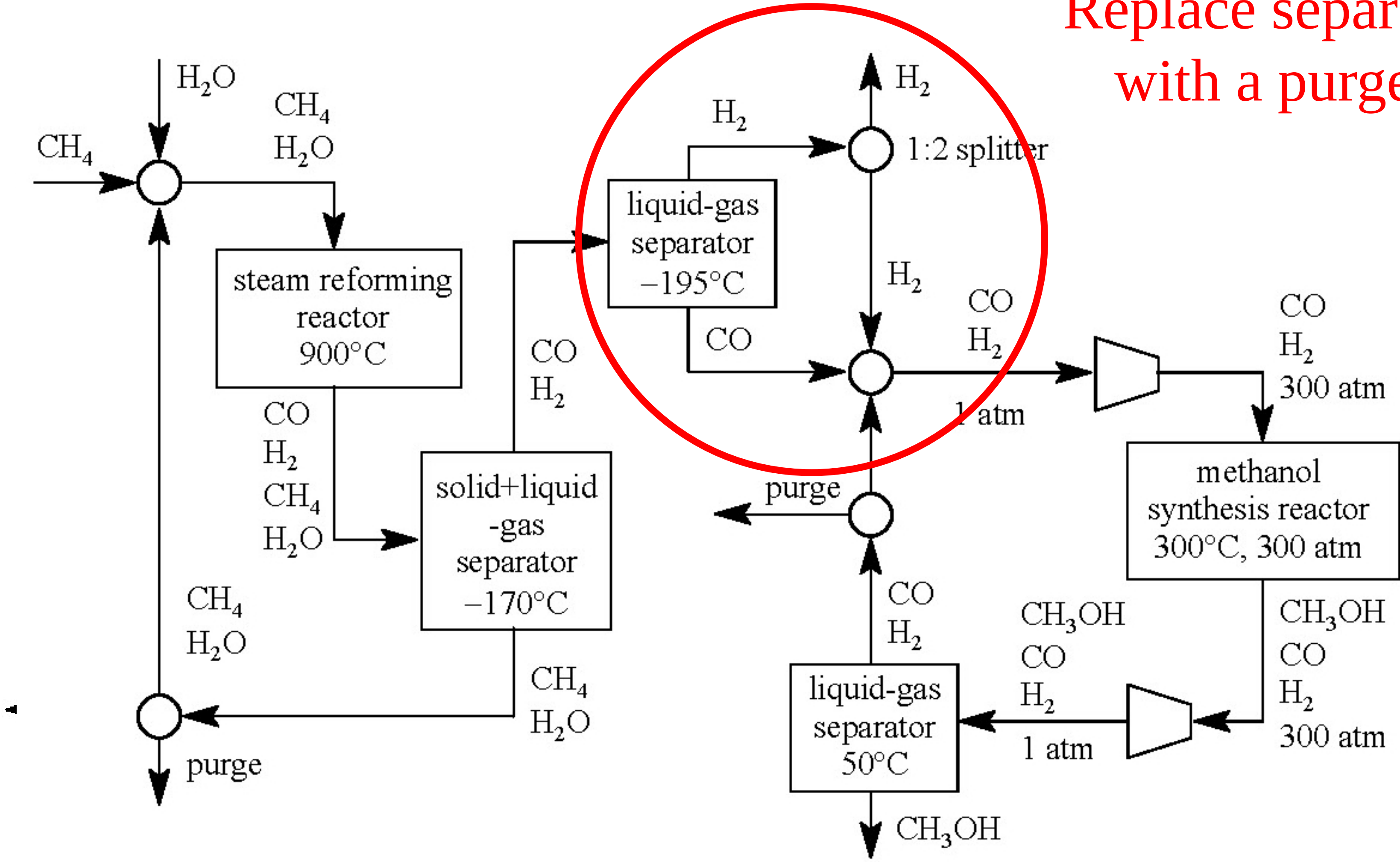
Exercise 3.126: Draft Design



Calculation Session 1 – Design Exercise 2.22(A)

Convert CH_4 to CH_3OH

Replace separator with a purge?



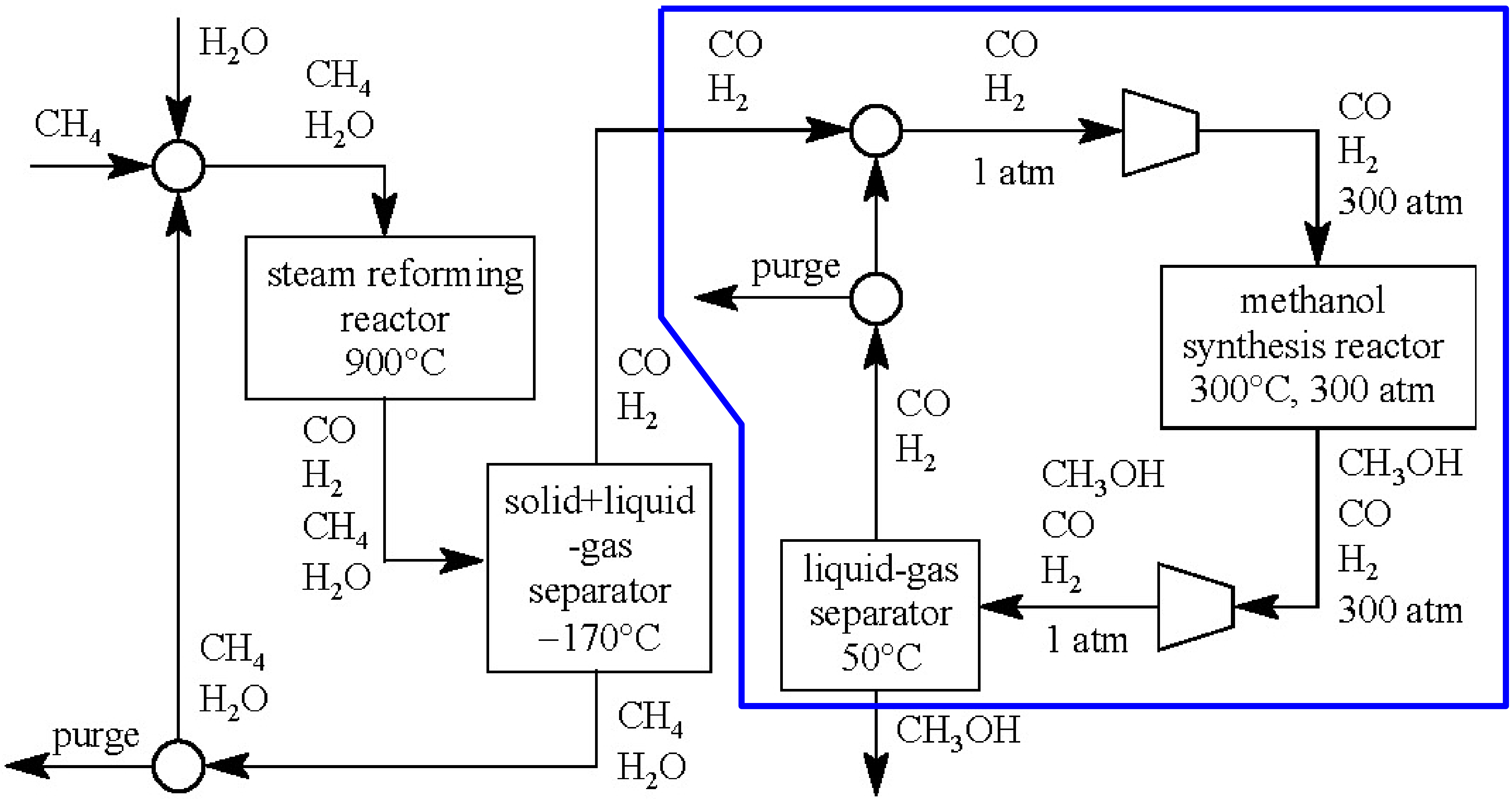
$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$CO + 2H_2 \rightarrow CH_3OH$$

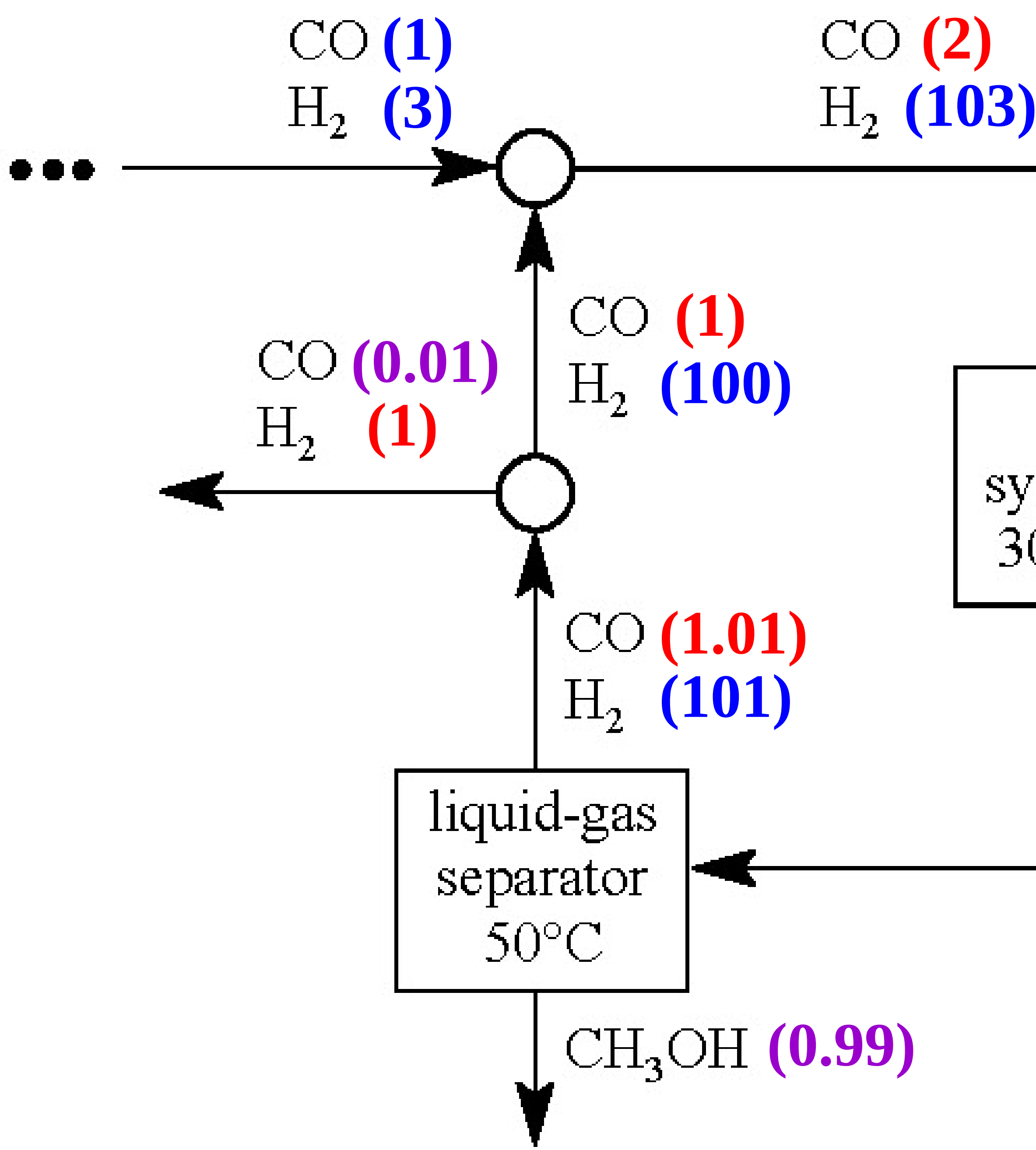
$$\text{sum: } CH_4 + H_2O \rightarrow CH_3OH + H_2$$

Must remove some H_2.

Exercise 2.22: How to remove H_2 via the purge?

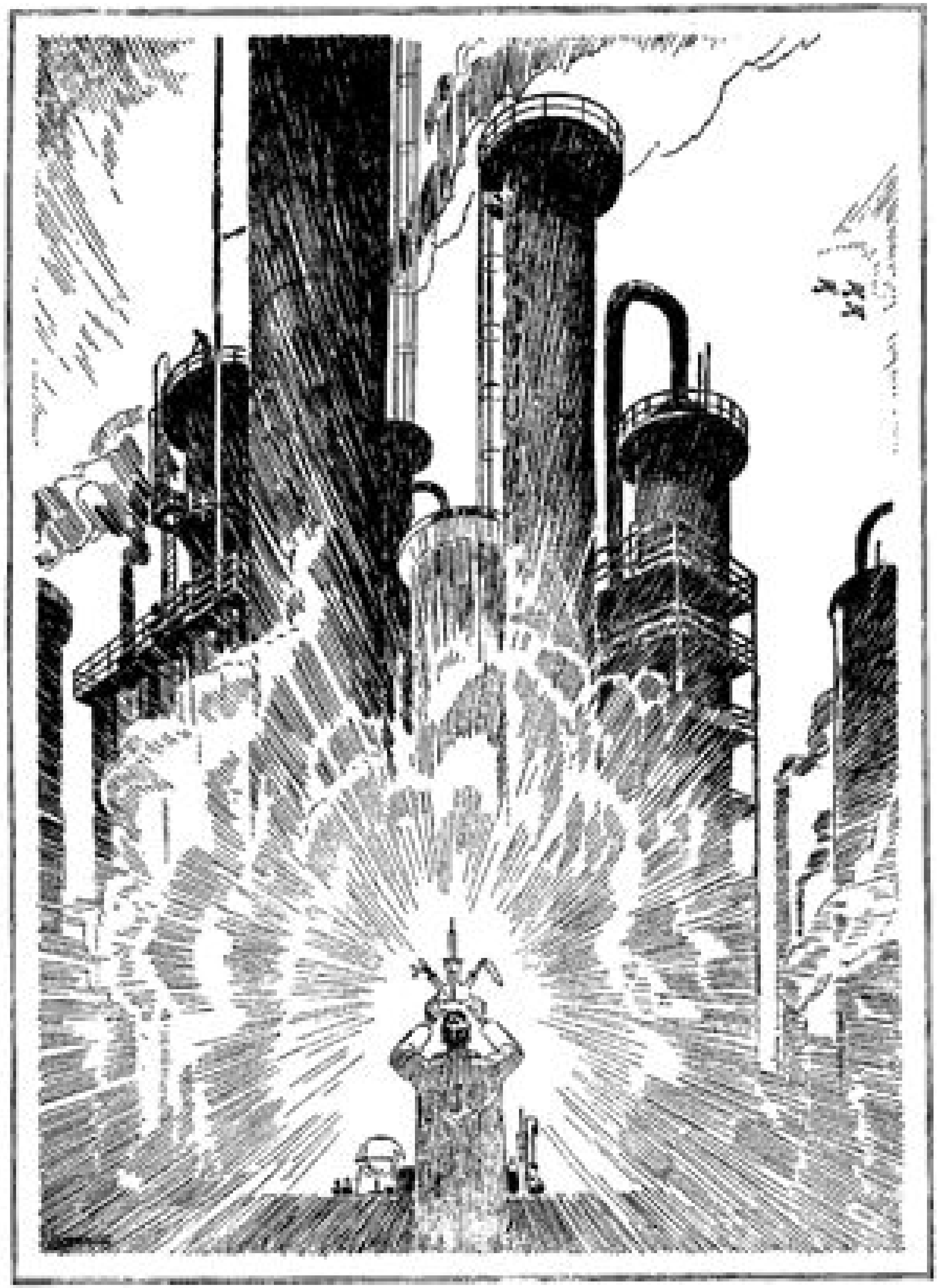


Exercise 2.22: How to remove H_2 via the purge?

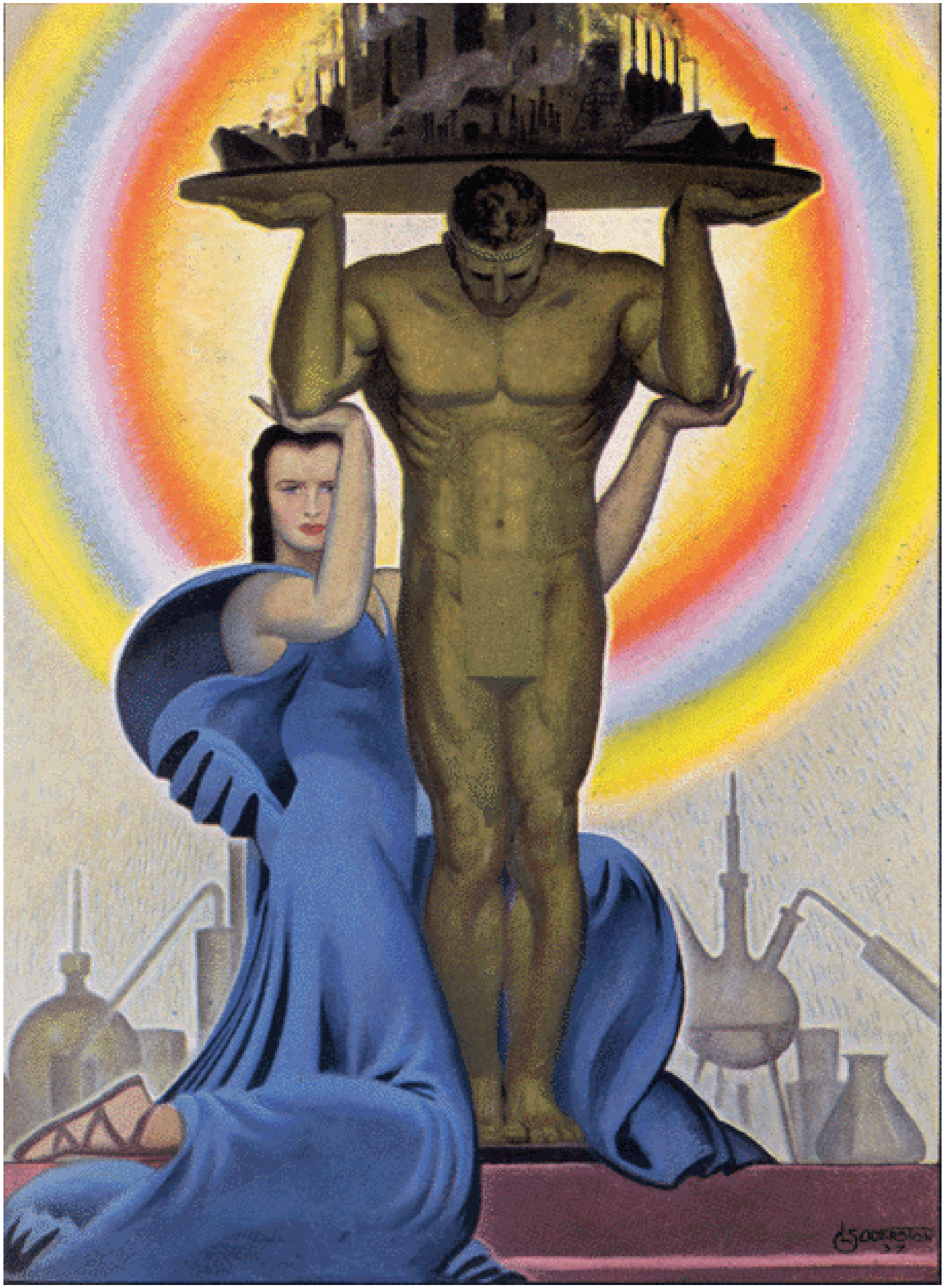


Assume 50% conversion of CO in reactor

Better Design?



Man in a Chemical World: The Service of Chemical Industry, A. Cressy Morrision (1937). Illustrator Leon Soderston.



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