# Recycling Systems Engineering

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# Science and Engineering of Material Reuse

- Benefits
  - Environment
  - Conservation
  - Cost reduction
  - Competitiveness

- Issues
  - How to design a recycling system
  - Guidelines for manufacturers — Design for Recycling/Reuse
    - Certain combinations of materials must be discouraged or forbidden.
  - How to provide incentives

Collaborators:

- MIT: Tim Gutowski, Stan Gershwin, Malima Wolf
- Politecnico di Milano: Marcello Colledani, Amedeo Grotti, Davide Veroux

## *Components of a Recycling System*

- Comminution
  - Breaks large particles into small particles: grinding, shredding, pulverizing, etc. (Small particles are often easier to work with than large ones.)
  - Increases the fraction of homogeneous *(liberated)* particles.
- Separation
  - Splits a mixed input stream into two or more output streams in which the concentration of a target material is greater than in the input stream.

 

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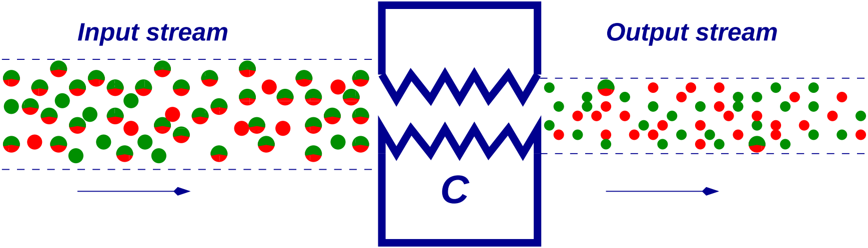
*Comminution*

- The size of the particles in the output stream depends on static parameters (the kind of process, the number and geometry of tools, etc.), dynamically controllable parameters (speed, pressure, etc.), and specified parameters (the composition of the input stream, the rate of flow, etc.).



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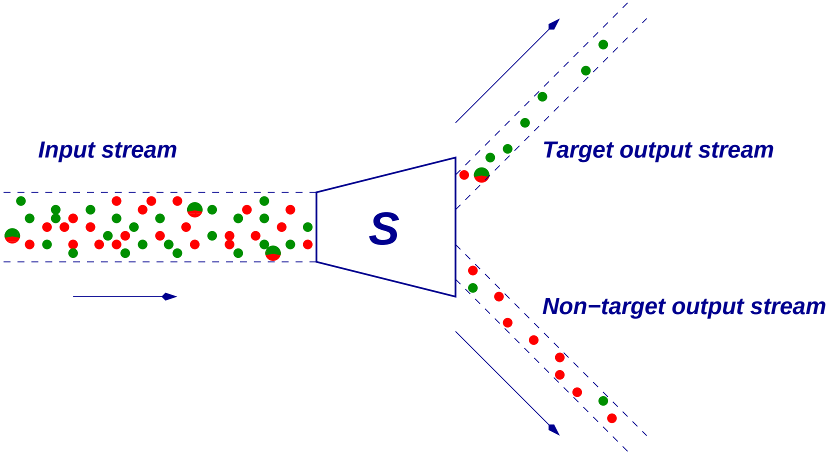
## *Separation*



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- Separation makes use of a *property* (conductivity, magnetism, density, color, particle size, etc.) which has very different values in the target material and the non-target material.
- A separation process creates an environment in which particles with a high value of the property move differently from those with a low value of the property.

| Process | Property |
|---|---|
| Eddy current | Conductivity |
| Magnet | Magnetism |
| Flotation | Density |
| Sieve | Particle size |

 

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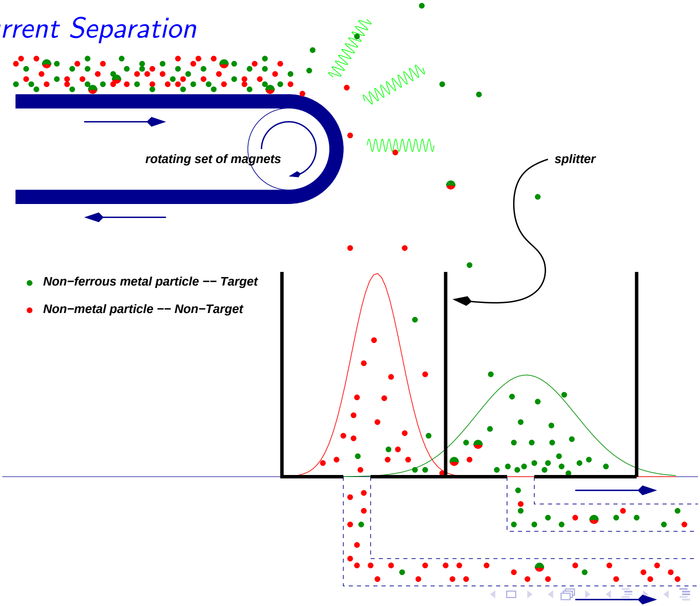
## *Eddy Current Separation*



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## *Separation*

- The quality of a separation process step is *indicated* by
  - $r$, the probability that a target material particle goes to the target output stream.
  - $q$, the probability that a non-target material particle goes to the non-target output stream.
  - *Compare with statistical hypothesis testing.*

## *Separation*

- The quality of a separation process step is *determined* by
  - static parameters (the separation property, the difference in the values of the property in the materials to be separated, the geometry and other implementation details, etc.),
  - dynamically controllable parameters (speed, strength of magnetic field, *separation threshold* , etc.), and
  - specified parameters (the composition of the input stream, the rate of flow, etc.).
- Separation steps based on different properties are needed if there are multiple target materials.

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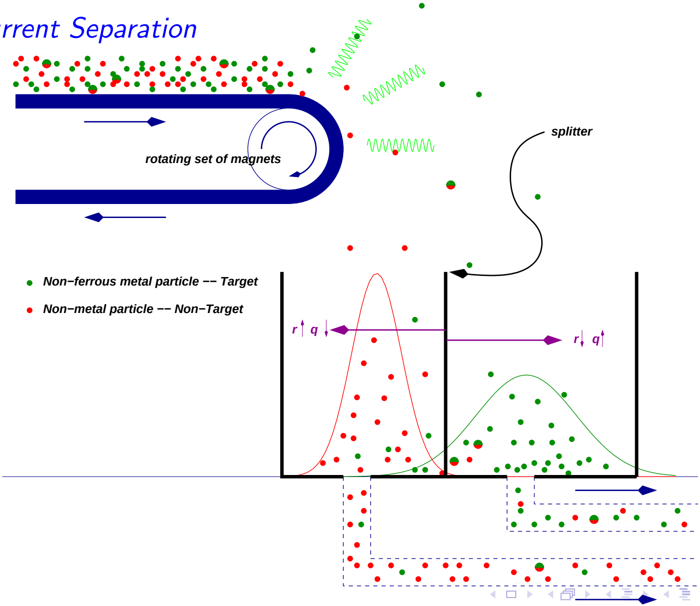
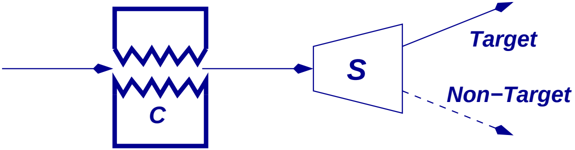
## *Eddy Current Separation*



*Separation Systems*

Separation systems have one or more separation steps ($S$), none or some comminution ($C$) steps.




*Problem:* Choose parameters of $C$ and $S$ to meet performance goals at minimum cost (including both capital and operating costs).

*System performance measures:* purity, recovery, flow rate, energy consumption

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## *Separation Systems* — Challenges

- Modeling $C$ processes to predict output particle size and homogeneity as a function of process parameters, and predicting flow rate and energy consumption (and other costs).
- Modeling $S$ processes to predict $r$ and $q$ as a function of process parameters, and predicting flow rate and energy consumption (and other costs).
- Modeling the interaction between $C$ and $S$. For example,
  - smaller particles from $C$ increases the fraction of homogeneous particles, which *improves* separation, but ...
  - smaller particles in $S$ may have physical properties that *degrade* separation. (In flotation, surface tension prevents small particles from sinking, even if they are dense. They are then not separated from light particles.)

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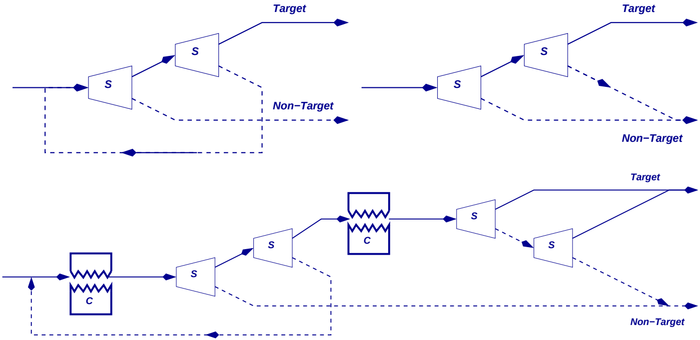
## *Separation Systems*

- ... may have one or more $S$ steps, none or more $C$ steps.




- ... may have multiple $S$ steps with the same property, or with different properties.

*Separation Systems — Goals of Analysis*

- Prediction of performance and cost of a proposed design
- Optimization of design

## *Separation Systems — Approaches*

- High level
  - Very aggregated — considers bulk flows
  - Models include conservation of flow and statistics of separation
  - Efficient for large systems
  - Attempts to treat different processes in a unified framework
  - Currently the framework only includes separation

## *Separation Systems — Approaches*

- Low level
  - Very detailed — considers individual particles
  - Models based on physics and empirical data
    - Trajectories of particles due to induced eddy currents; energy of shredding, etc.
  - Treats both comminution and separation
  - Currently the only separation process studied is eddy current

## Future Work

- Complete eddy current model.
- Analyze additional separation processes including
  - Magnets
  - Flotation
  - Sieves
- Continue development of comminution model.
- Analyze specific comminution processes.
- Continue development of system models.
- Continue development of system optimization methods.
- Work with industry:
  - Obtain data to develop and validate models.
  - Perform case studies.
  - Assist with system design.

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