MINE 432 Introduction to Process Control

John A. Meech

Professor and Director of CERM3

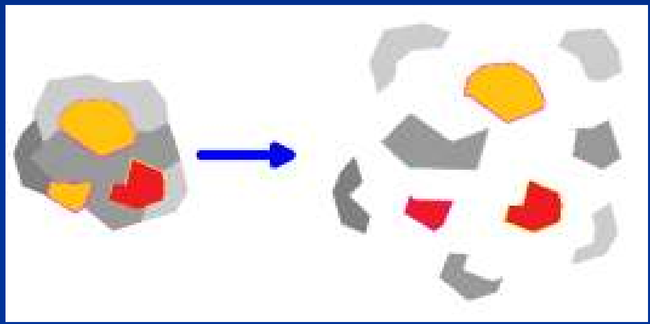
Centre for Environmental Research in Minerals, Metals, and Materials

To Be Ore, or Not to Be?

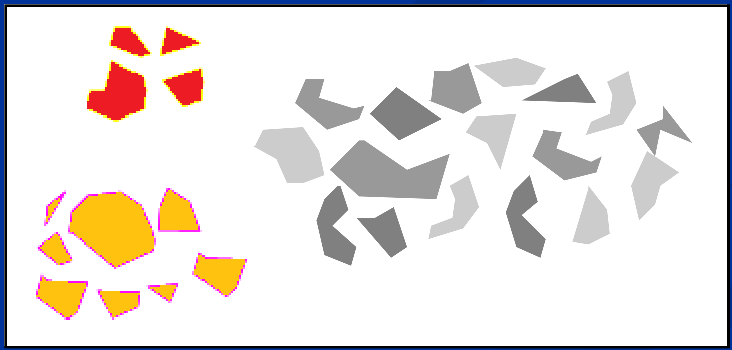
- An ore is a mixture of minerals, one or more of which has value, that can be mined:
  - At some time
  - At some place
  - For a profit
- What is not ore today, may become ore in the future
- What is ore in one place, may not be in another

Mineral Processing Stages

- Liberation (comminution or breaking of rock)
  - Blasting
  - Crushing
  - Grinding



- Separation (valuable minerals from waste)
  - Gravity
  - Magnetic
  - Electrostatic
  - Flotation



- Extraction of values from mineral concentrate

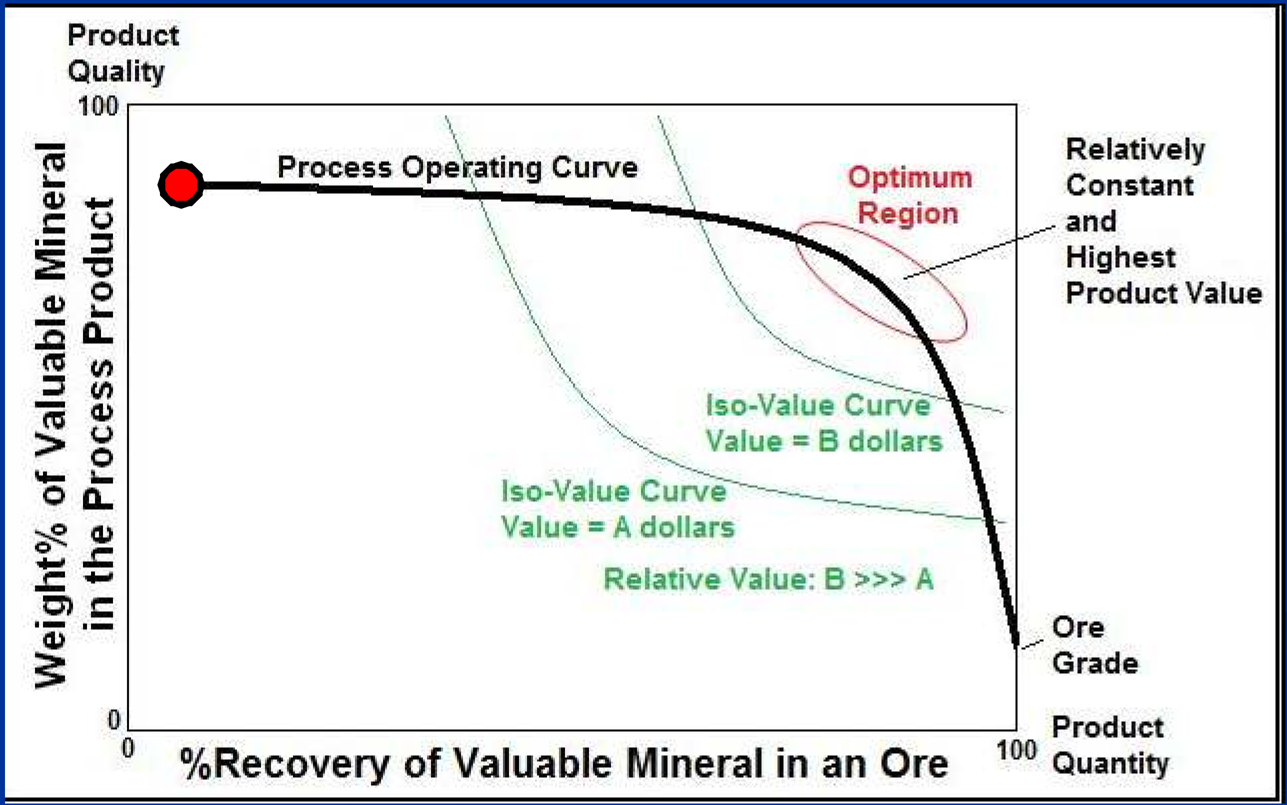
Operating Plant Targets

- Maximize **Product Quantity** (Production)
  - Tonnage rate of ore (say 100,000 tpd)
  - %Recovery of Valuable Component (say 92%)

- Maximize **Product Quality** (customer needs)
  - Concentrate grade (say 28 %Cu or 54 %Zn)
  - Impurity component levels (Bi, Sb, Pb in ppm)
  - %H_2O (both minimum and maximum)
  - Particle size constraints (top size and ultra-fines)

Grade vs. Recovery

- Often, there is a quality/quantity trade-off
- One goes up, the other goes down



Process & Instrumentation Diagrams

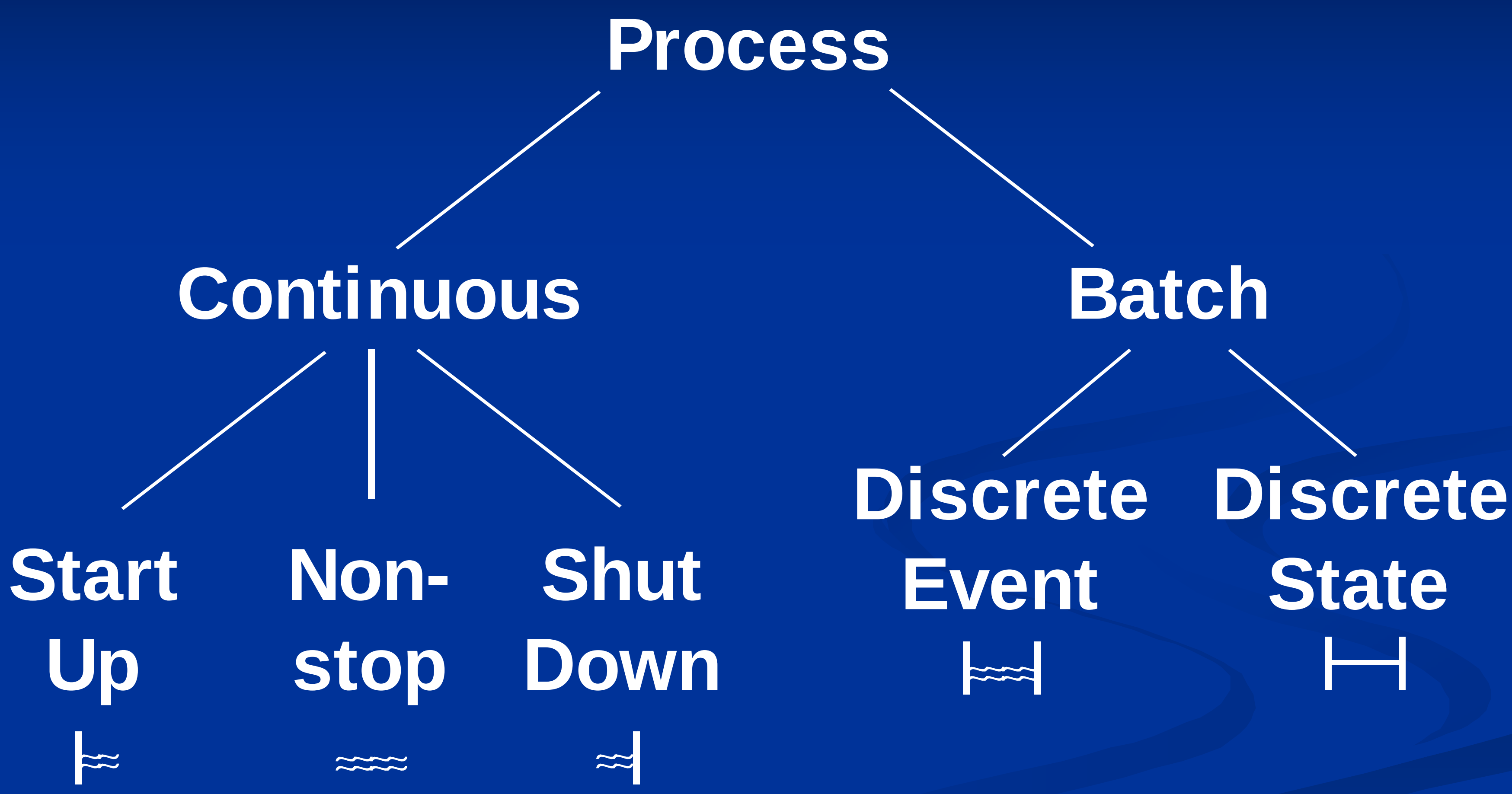
- Process diagrams depict a network of stages or events through which materials flow
- Process flowsheets represent unit operations through which solids, liquids, or gasses flow and are transformed
- Control system diagrams (or programs) represent stages in a system through which signals, information, or data flow

What is a Process?

A Process takes inputs and combines them in a way to produce one or more outputs

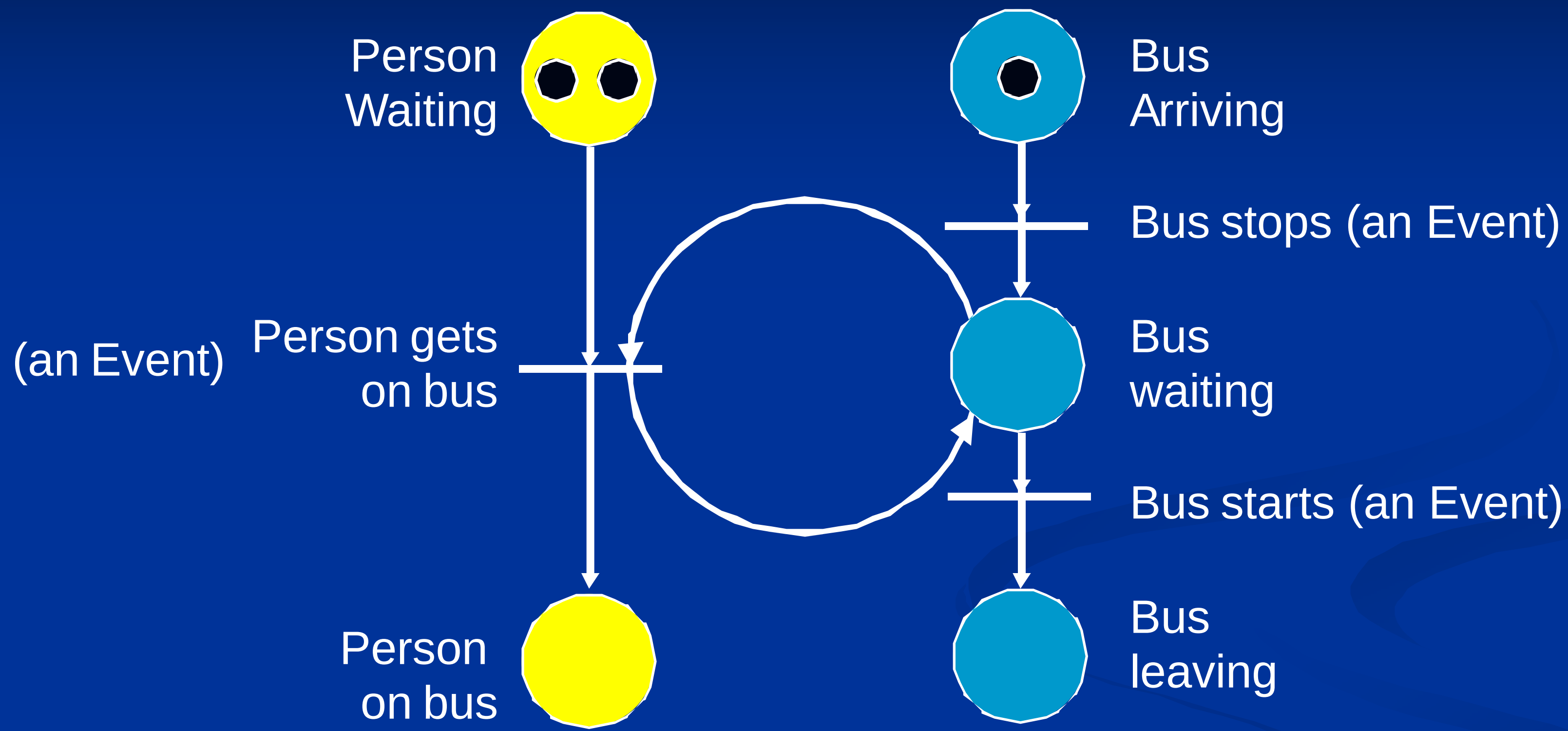
In process control, only a single input is involved in each block

What is a Process?



after: John Sowa, 2001. Processes and Causality, <www.jfsowa.com/ontology/causal.htm>

Batch or Discrete Process

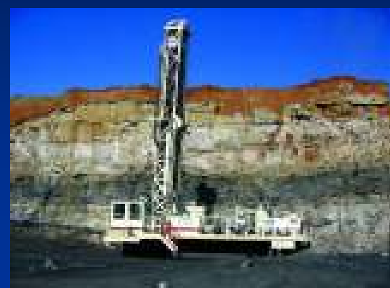


Execution of a Bus Stop Petri Net model (cumulative)

- works well with discrete agents/products represented as tokens

after John Sowa, 2001. http://www.jfsowa.com/ontology/causal.htm

Batch Processes in Mining



Drilling

Loading Explosives

Blasting

Digging

Loading Ore/Waste

Hauling Ore/Waste

Dumping Ore/Waste

Returning Empty

Maintenance

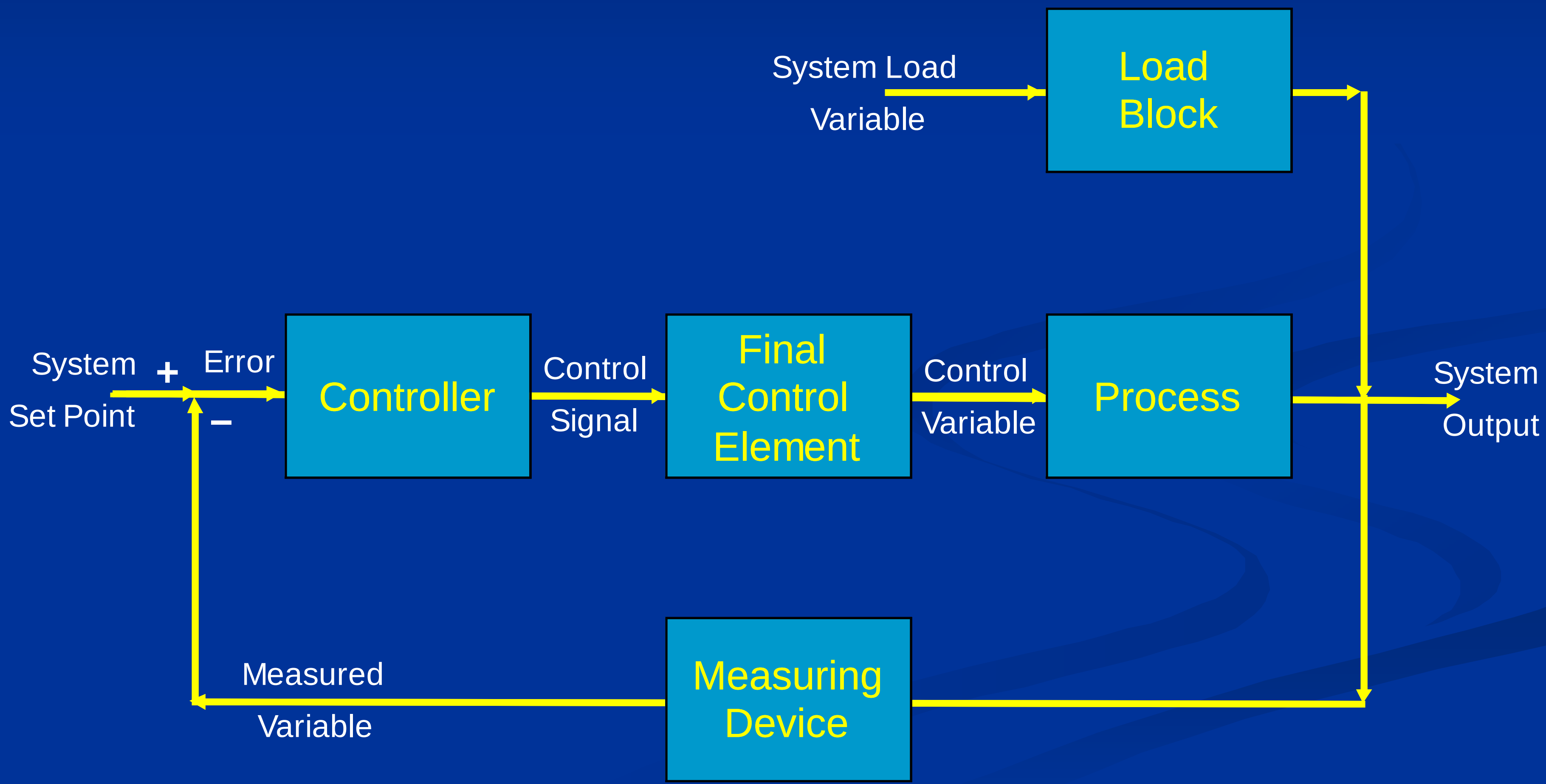
What is a Control System?

- A control system tries to keep an important process output variable as close to a target level (or set point) for as much of the time as possible
- The system responds rapidly and stably to compensate for changes in other variable that affect the output or to desired changes in the target level of the output

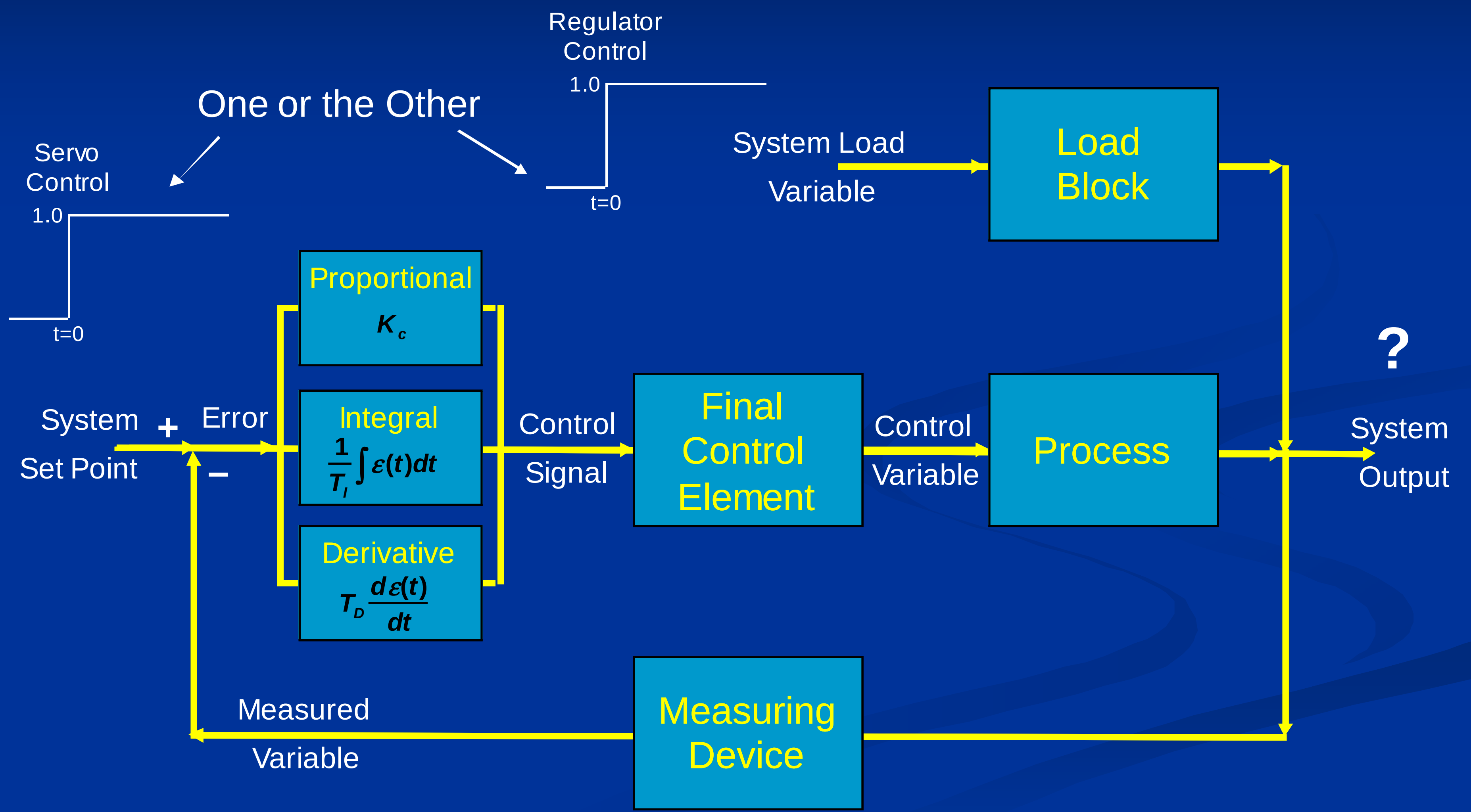
Why Control?

1. Increased Production Capacity
2. Increased Product Quality
3. Decreased Energy (Utility) Usage
4. Decreased Raw Material Usage
5. Reduction in Capital Investment
6. Savings in Equipment Maintenance and Replacement
7. Improved Safety and Improved Working Conditions
8. More Consistent and Predictable Plant Performance
9. Reduction in Labour Costs
   - by attrition and skills upgrading
   - where turn-over rates are high

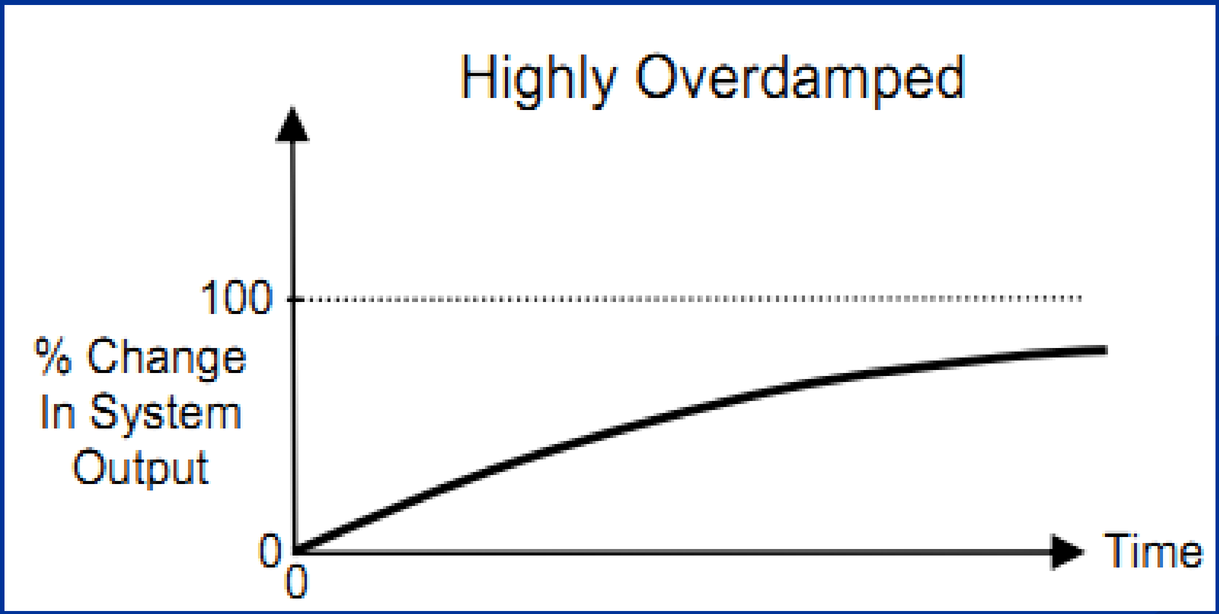
Elements of a Control System



Elements of a PID Control System



Response to a Set Point Step Change



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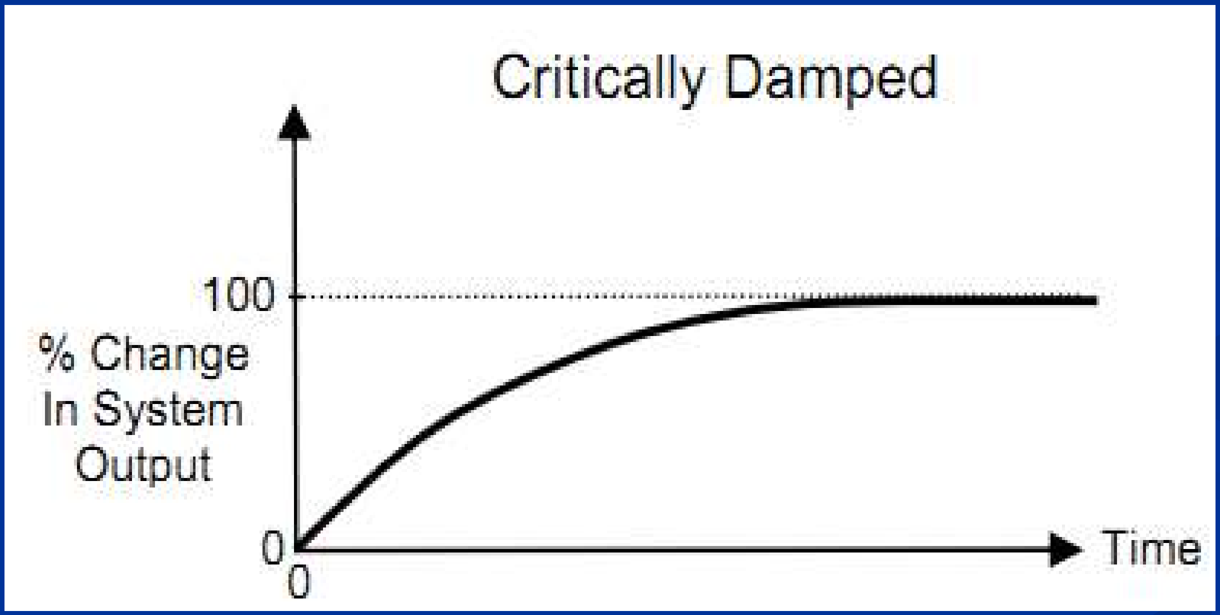

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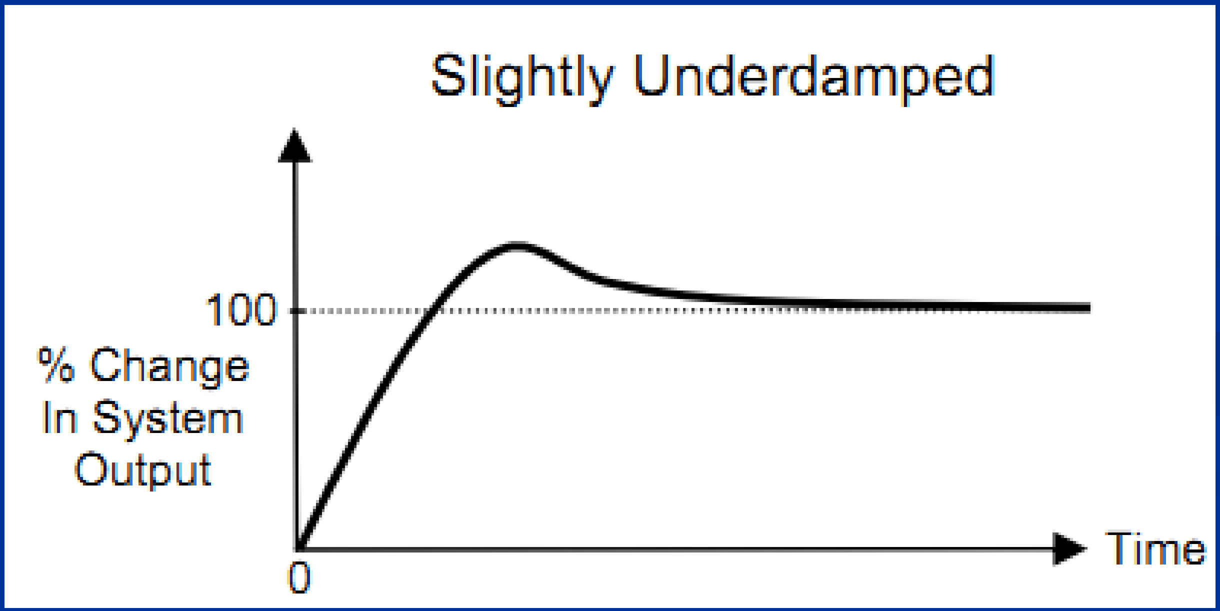

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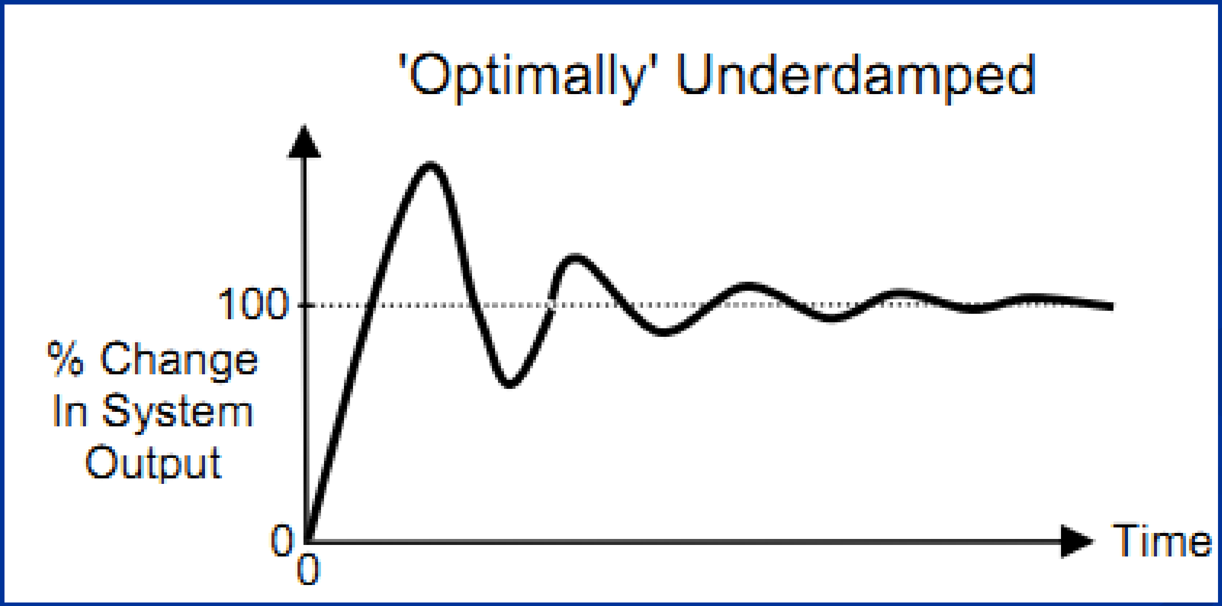

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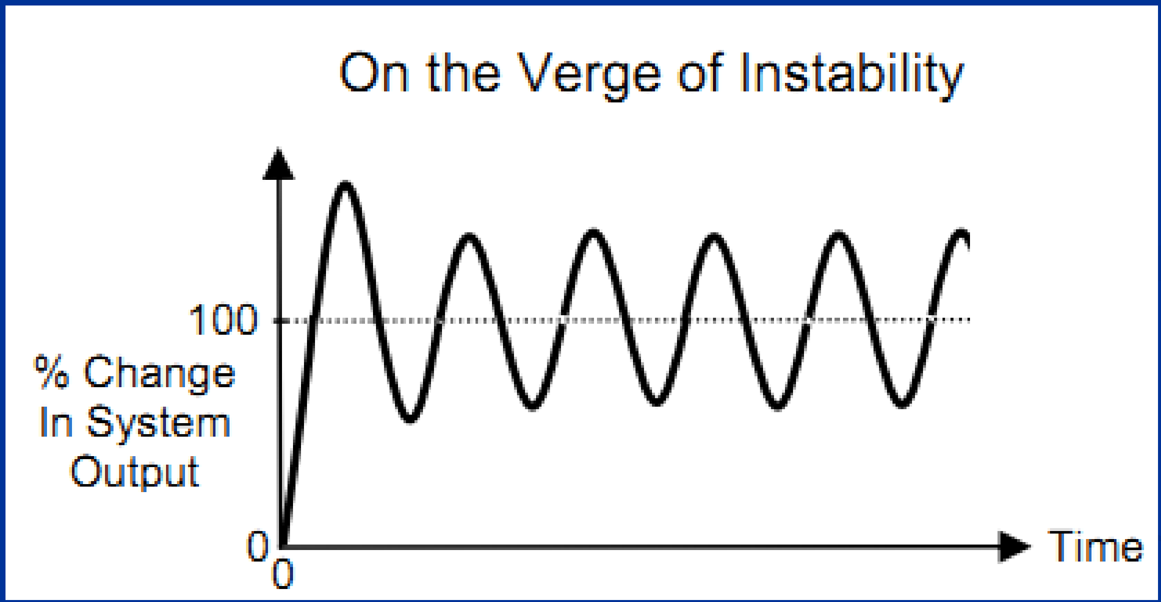

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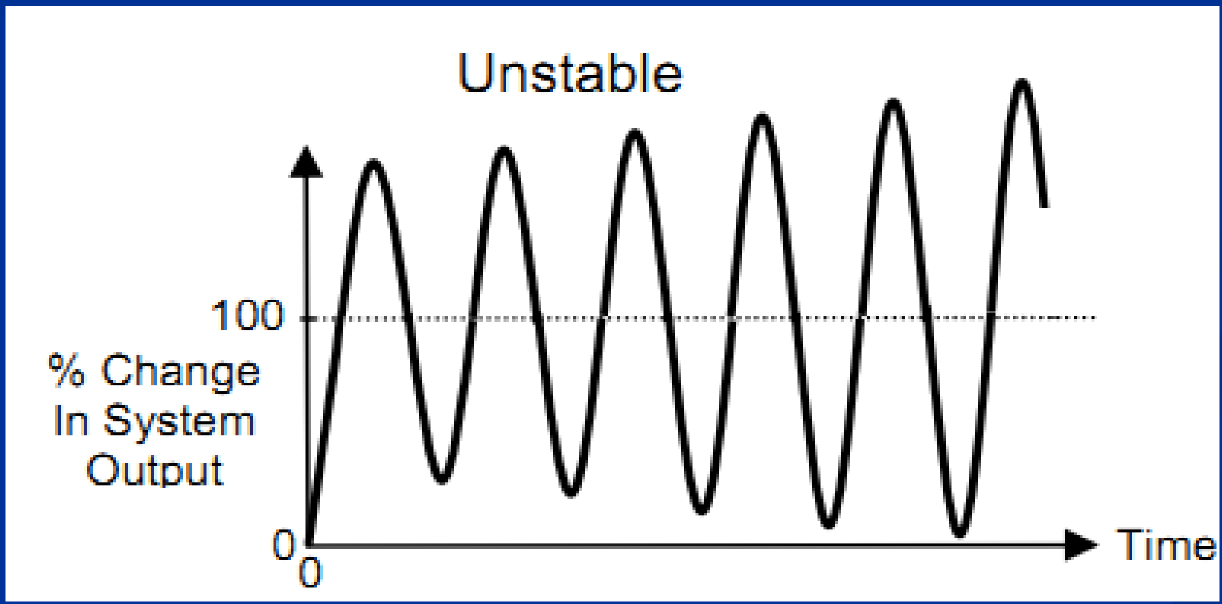
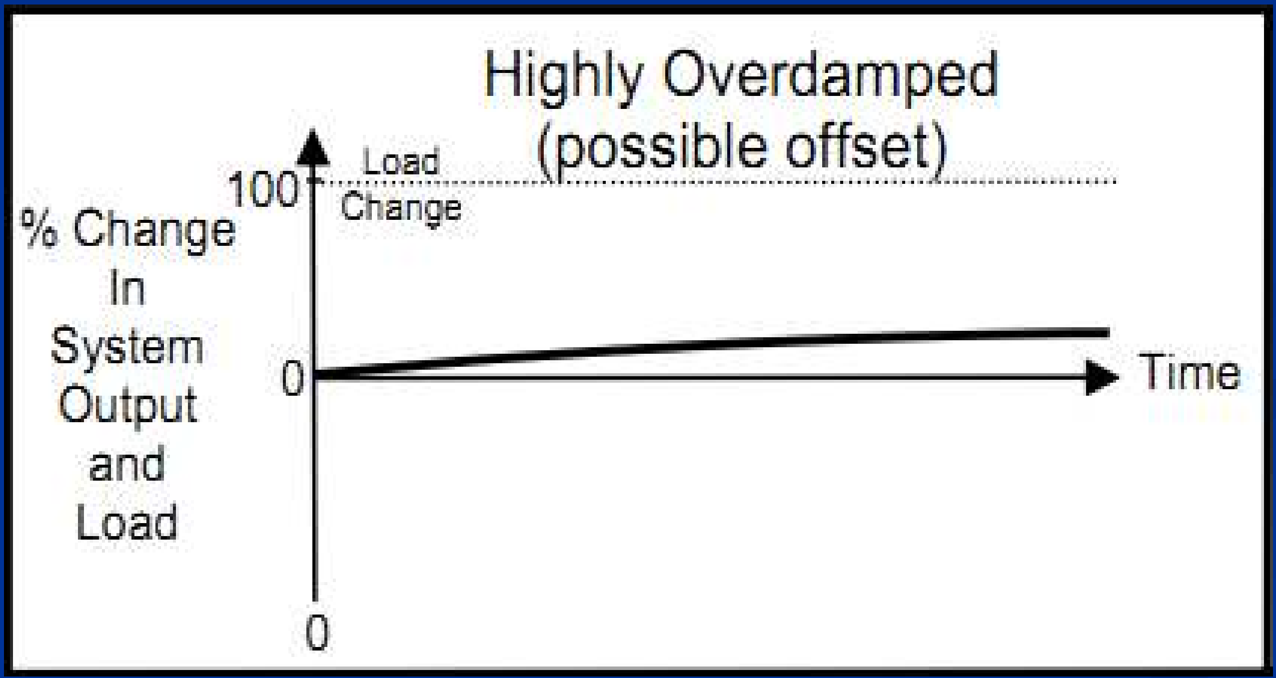


Response to a Load Step Change



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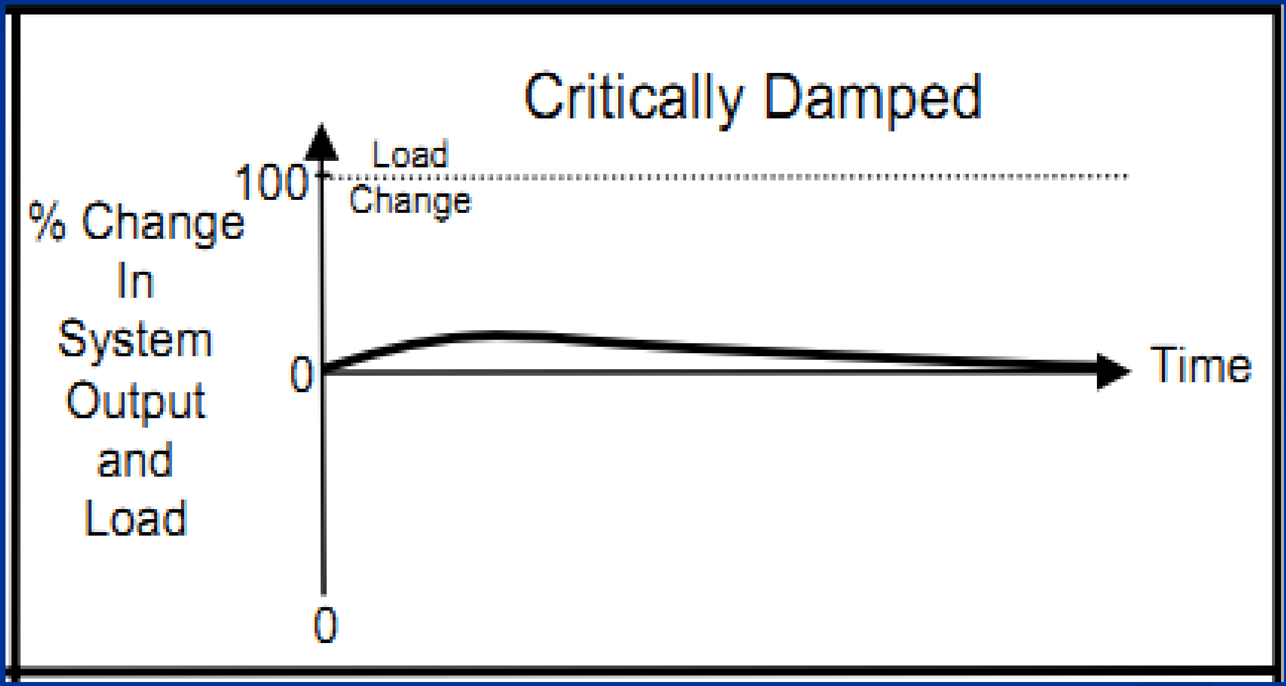

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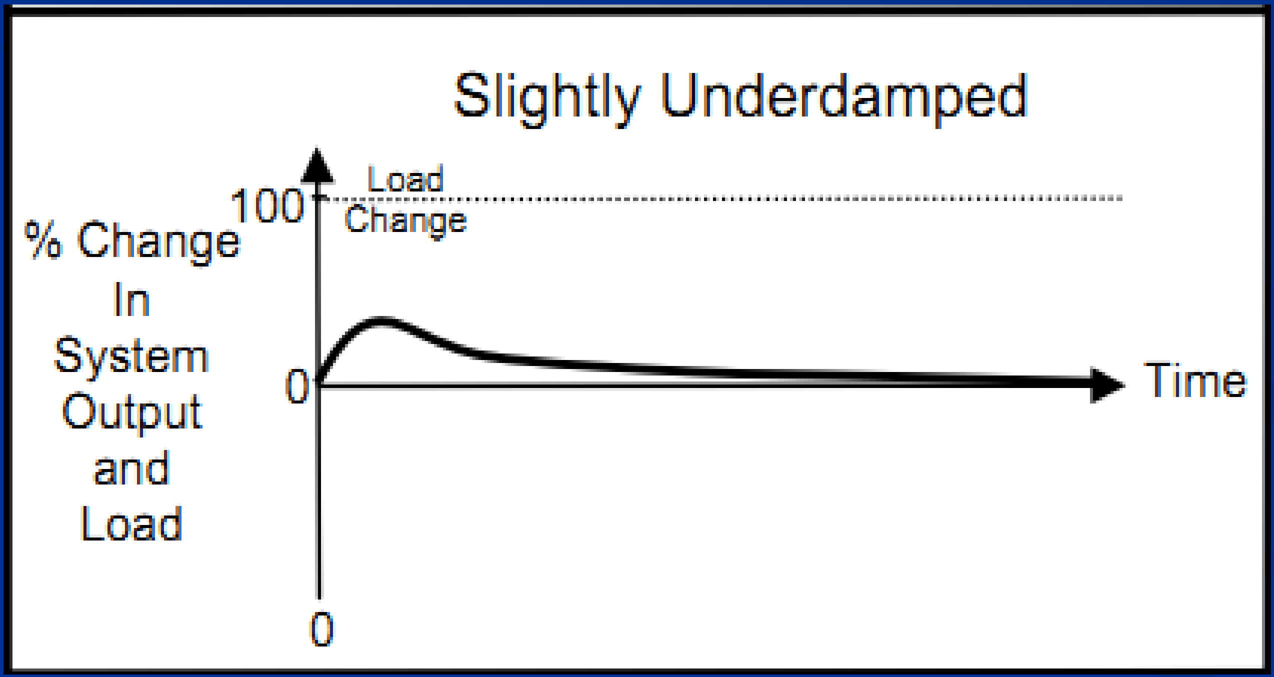
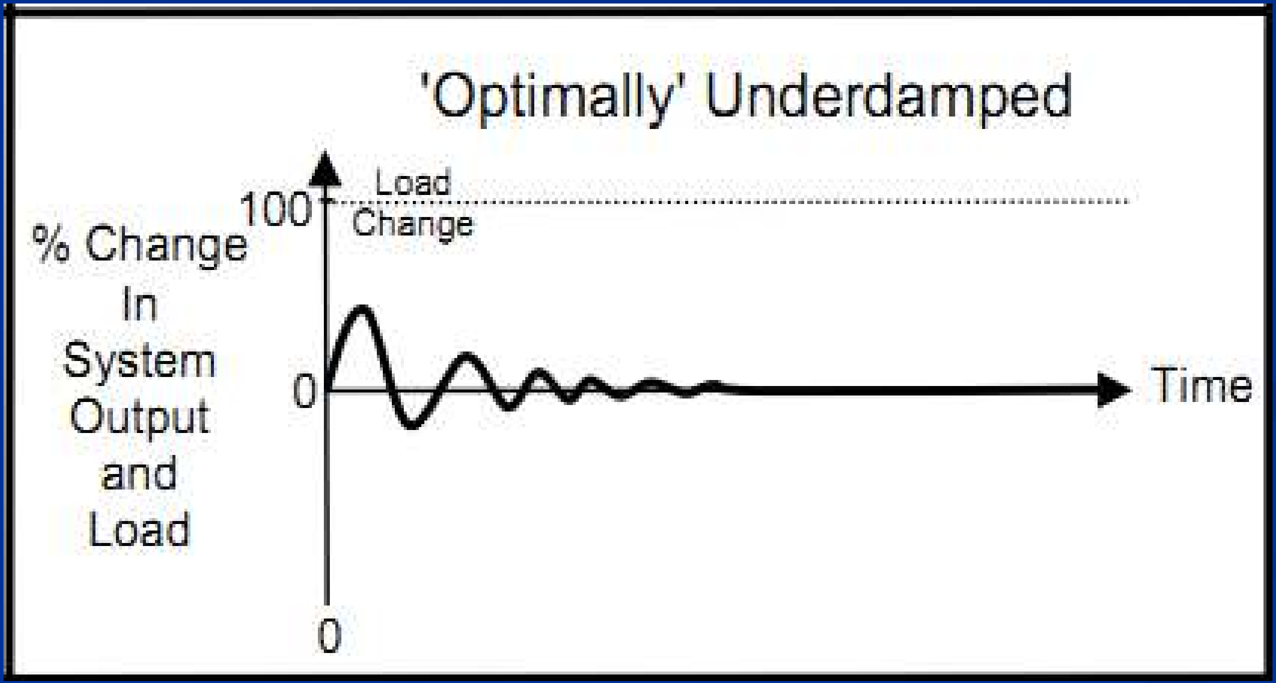


Response to a Load Step Change



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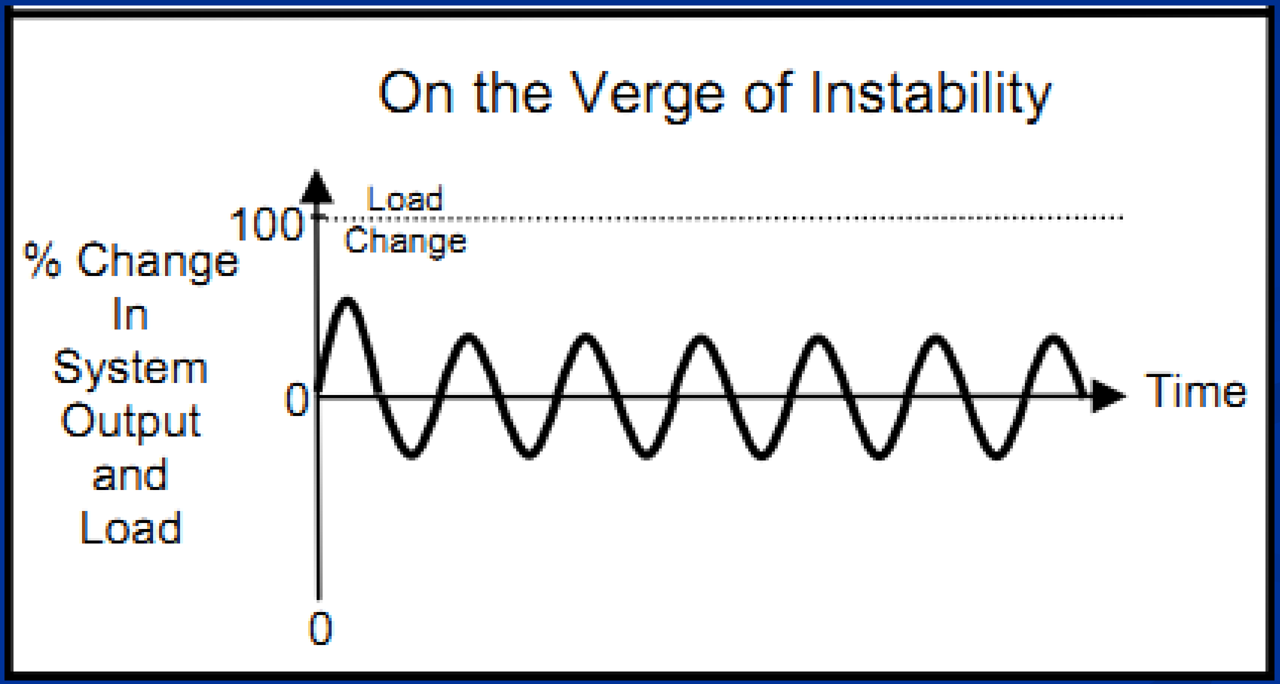

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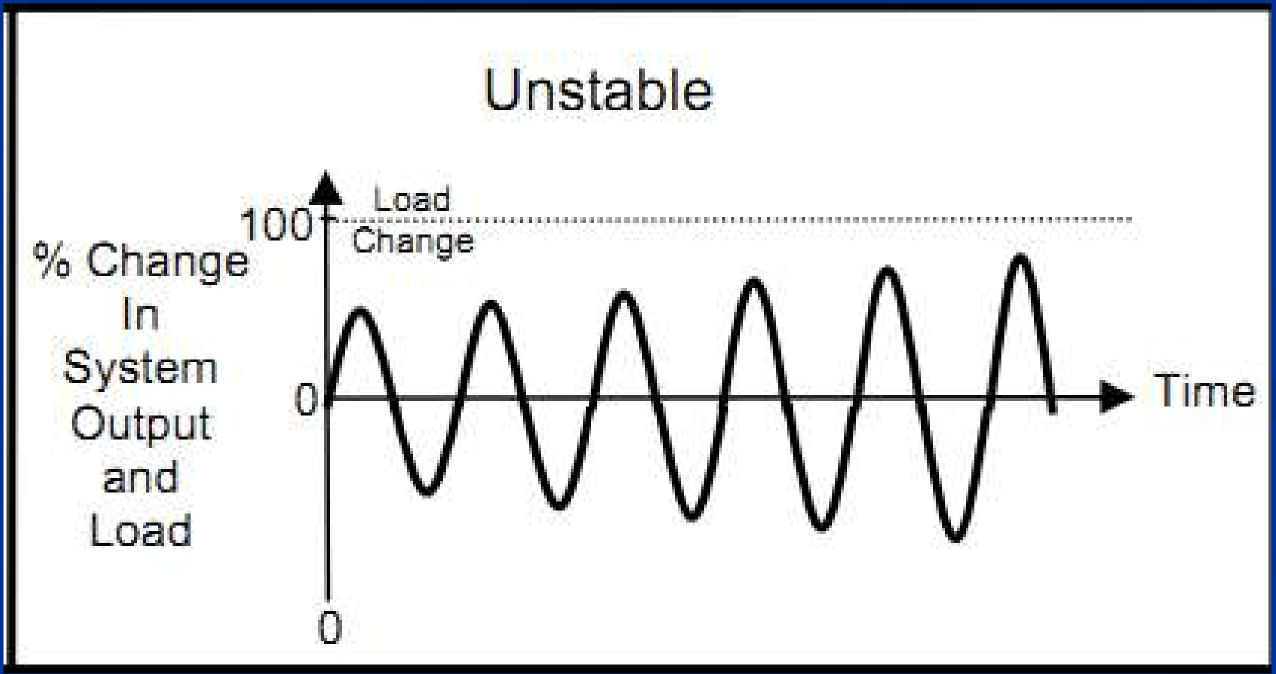
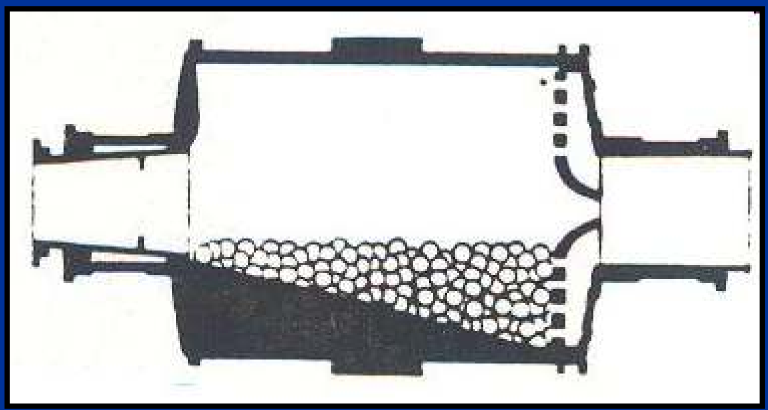


Unit Operation – grinding

- Ball-mill
  - rotating drum with steel balls cascading onto the rocks to break them into finer particles

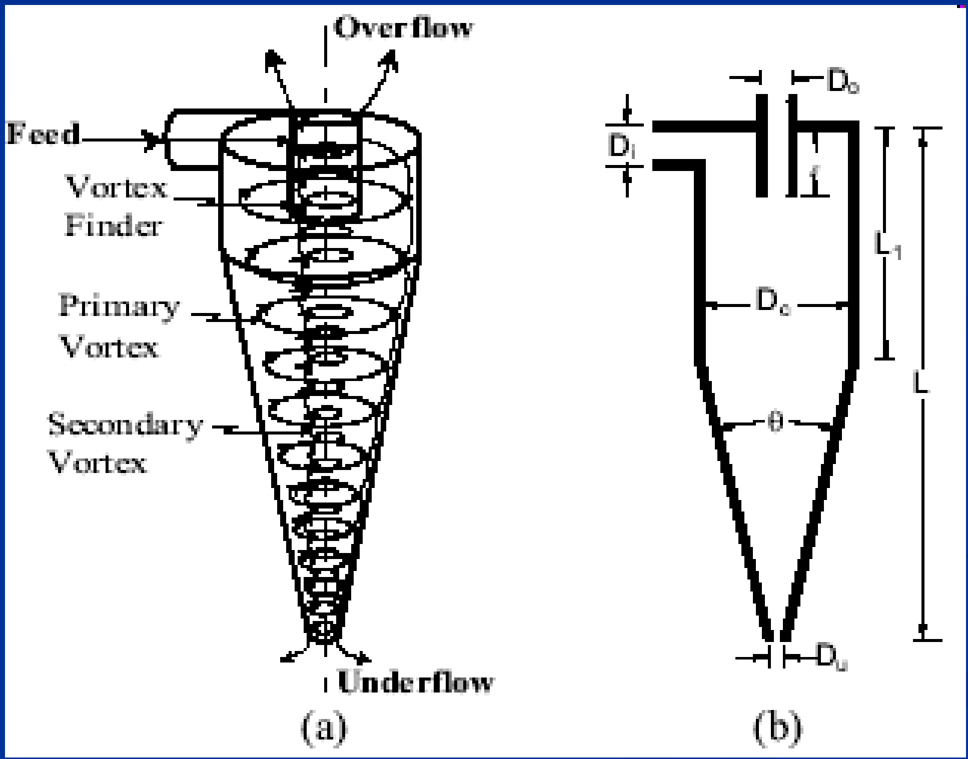


Grate-Discharge

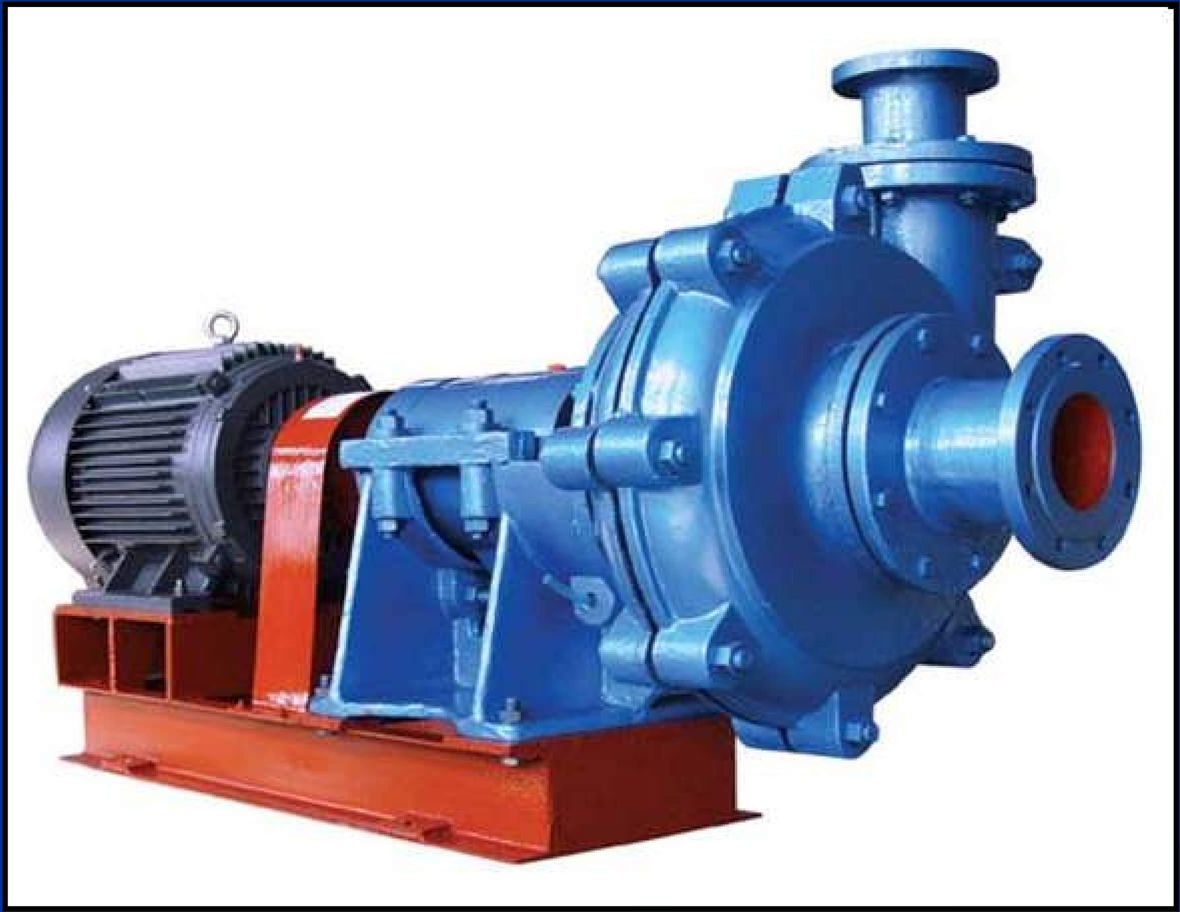
Typical Installation showing Covered Trunnion and associated Electric Motor

Unit Operation – size separation

- Hydrocyclone – separation by size



Unit Operation – slurry pump

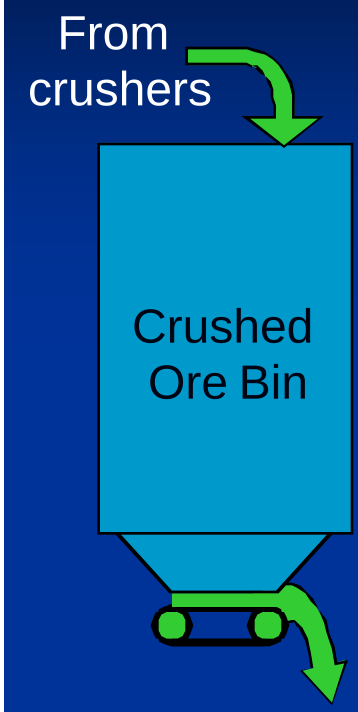


Variable Frequency Drive Slurry Pump

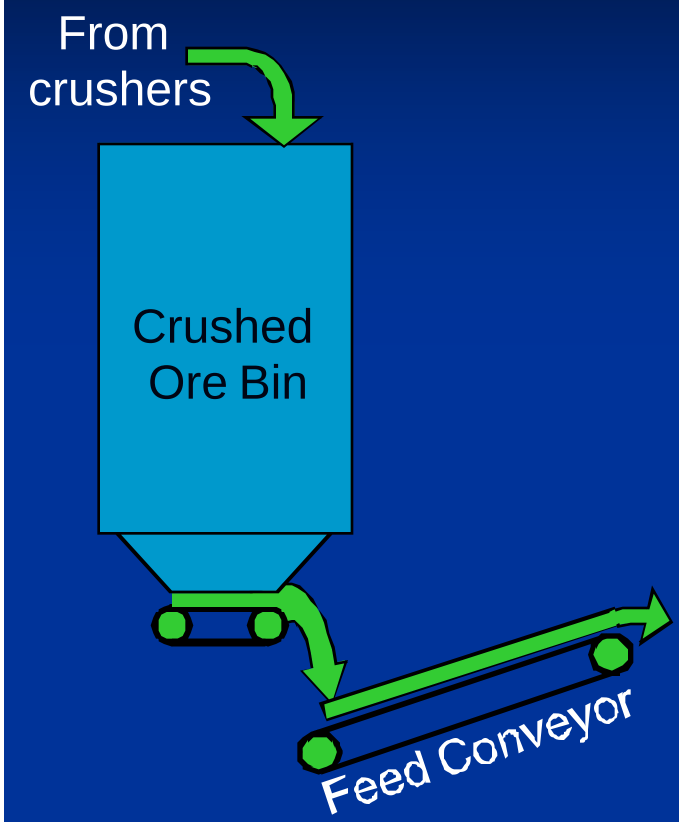
Unit Operation – conveyor belt

Conveyor belt feeding a stacker/reclaimer

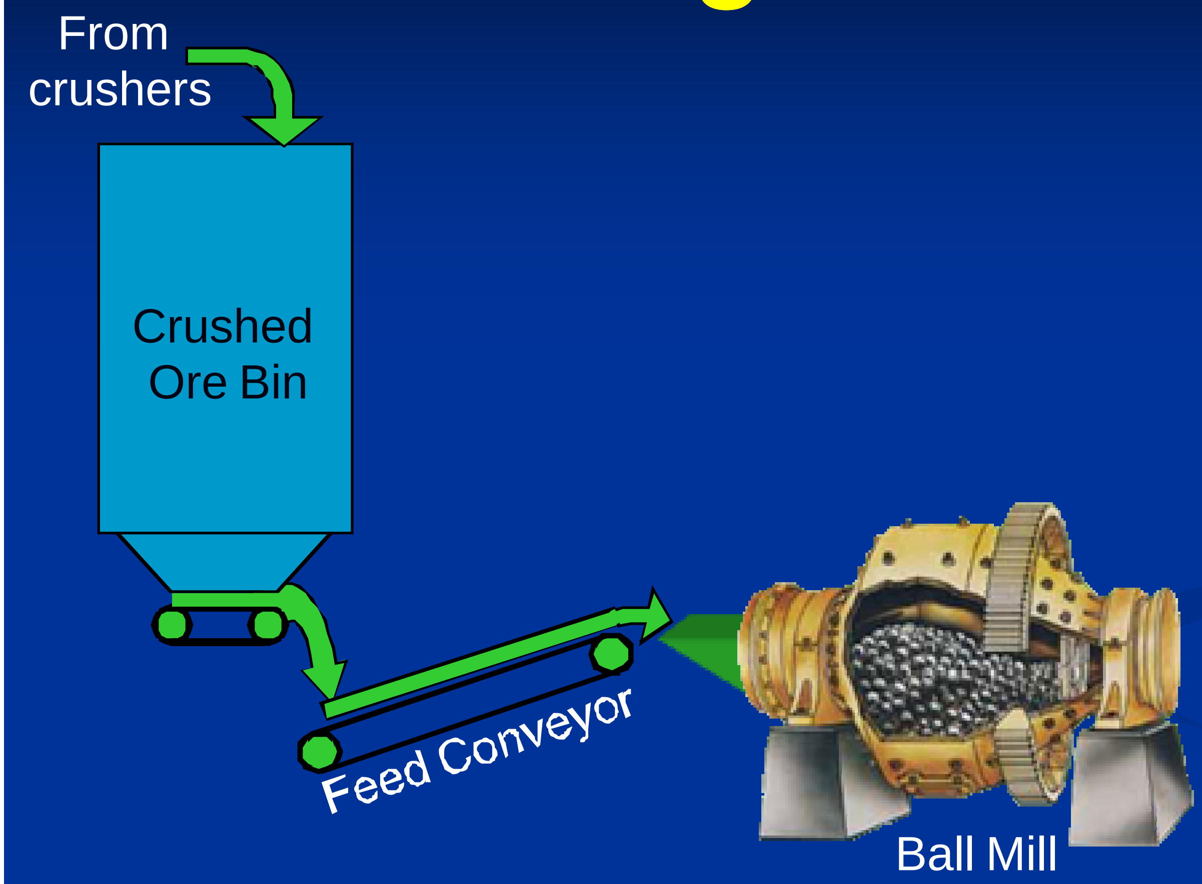
Building a Flowsheet - 1



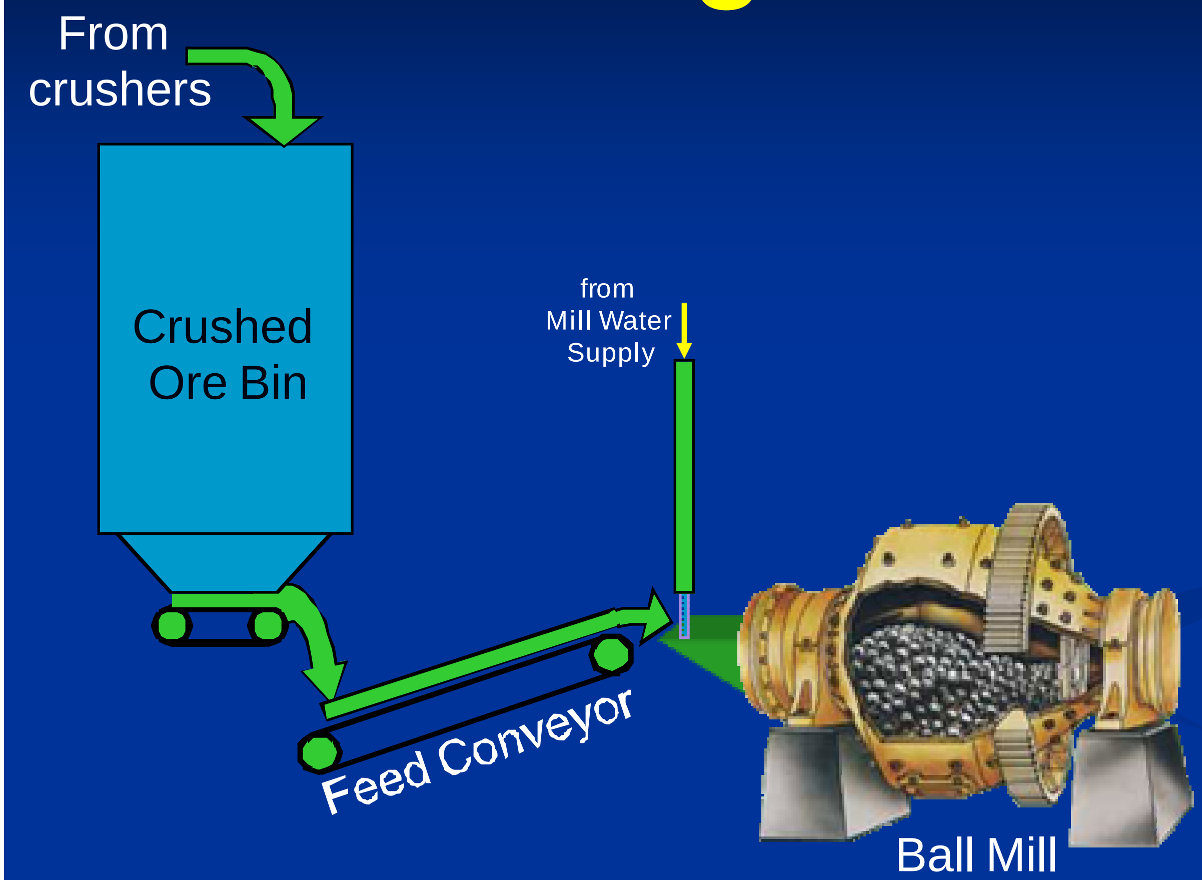
Building a Flowsheet - 2



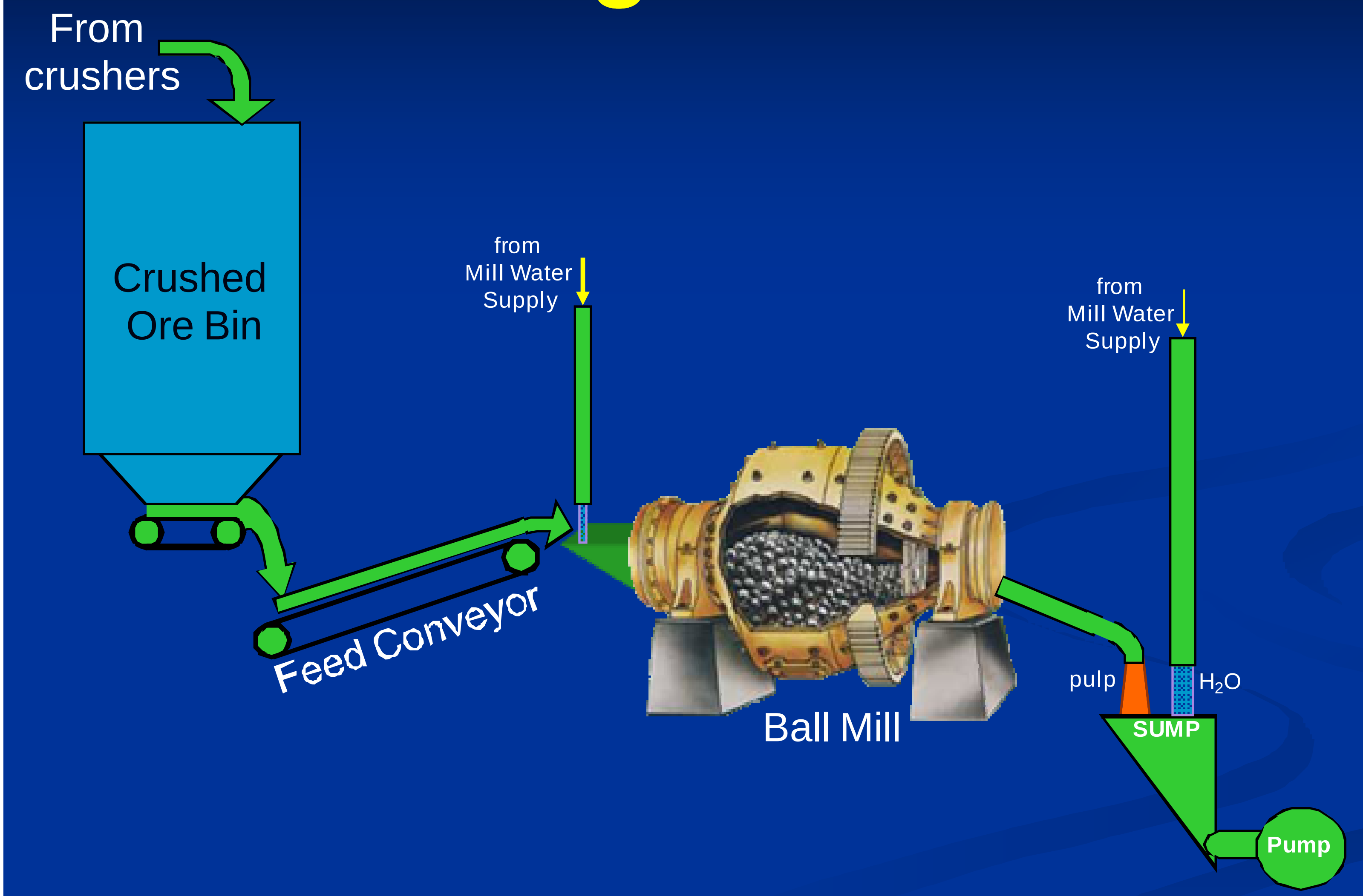
Building a Flowsheet - 3



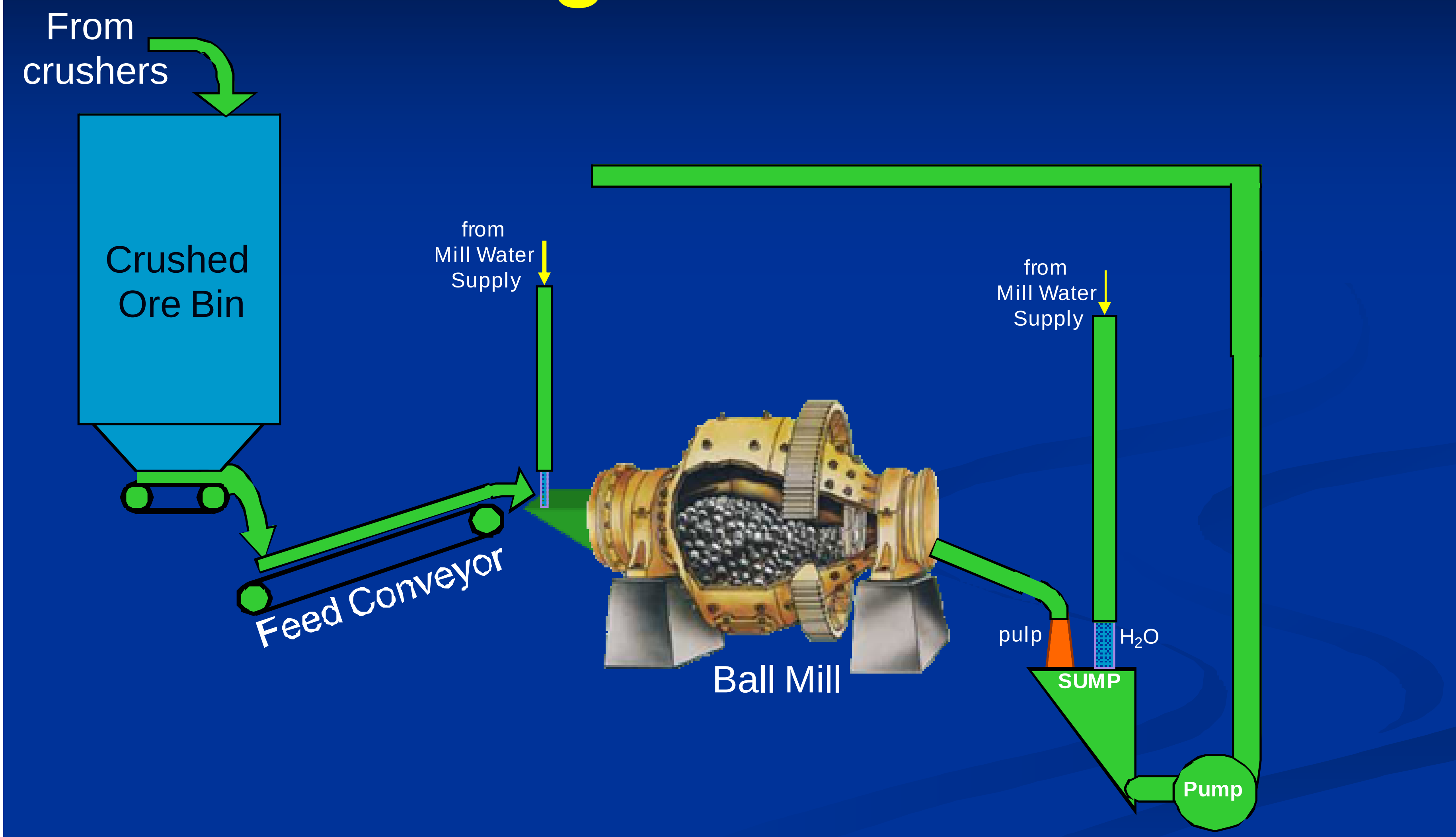
Building a Flowsheet - 4



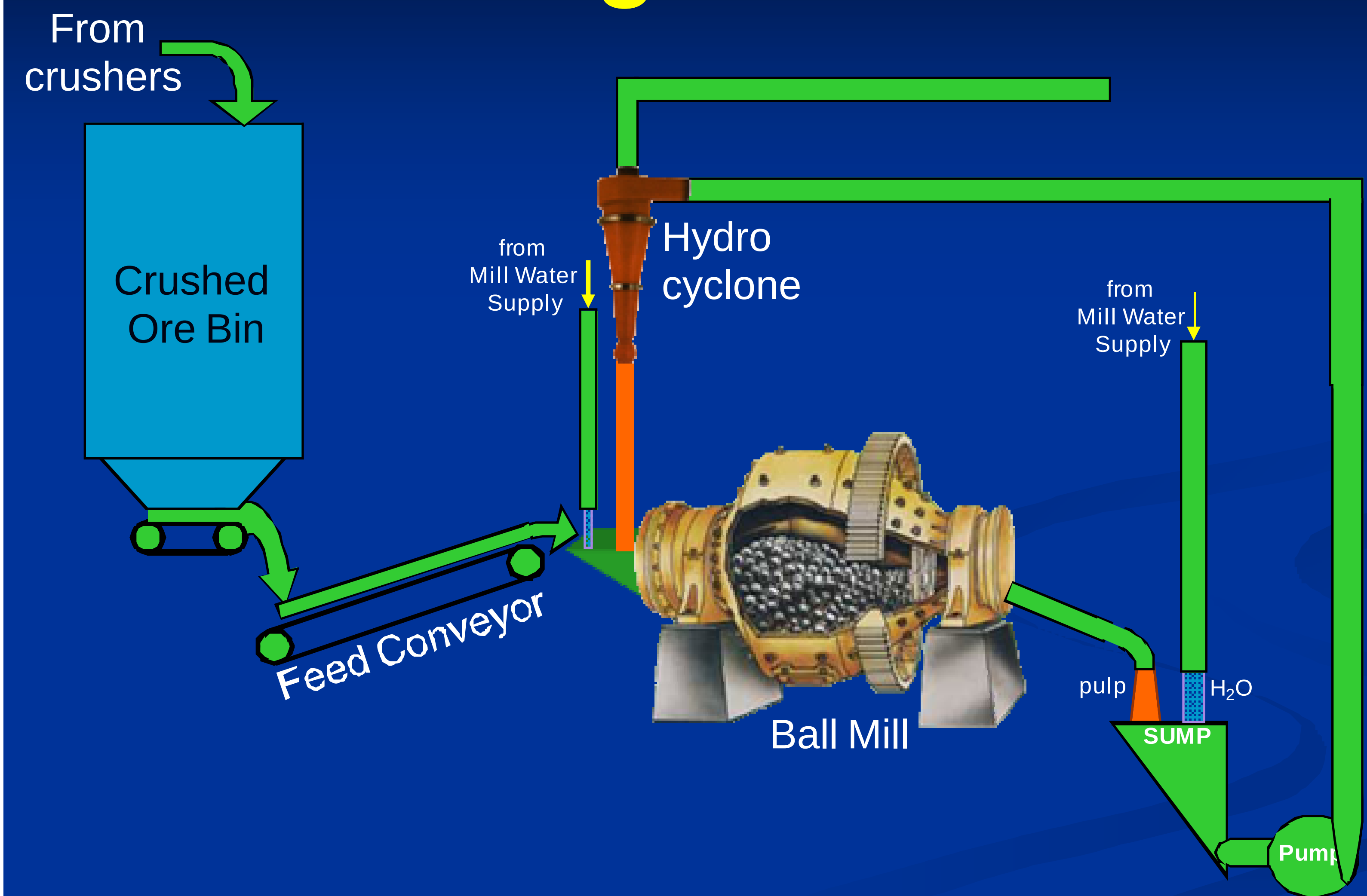
Building a Flowsheet - 5



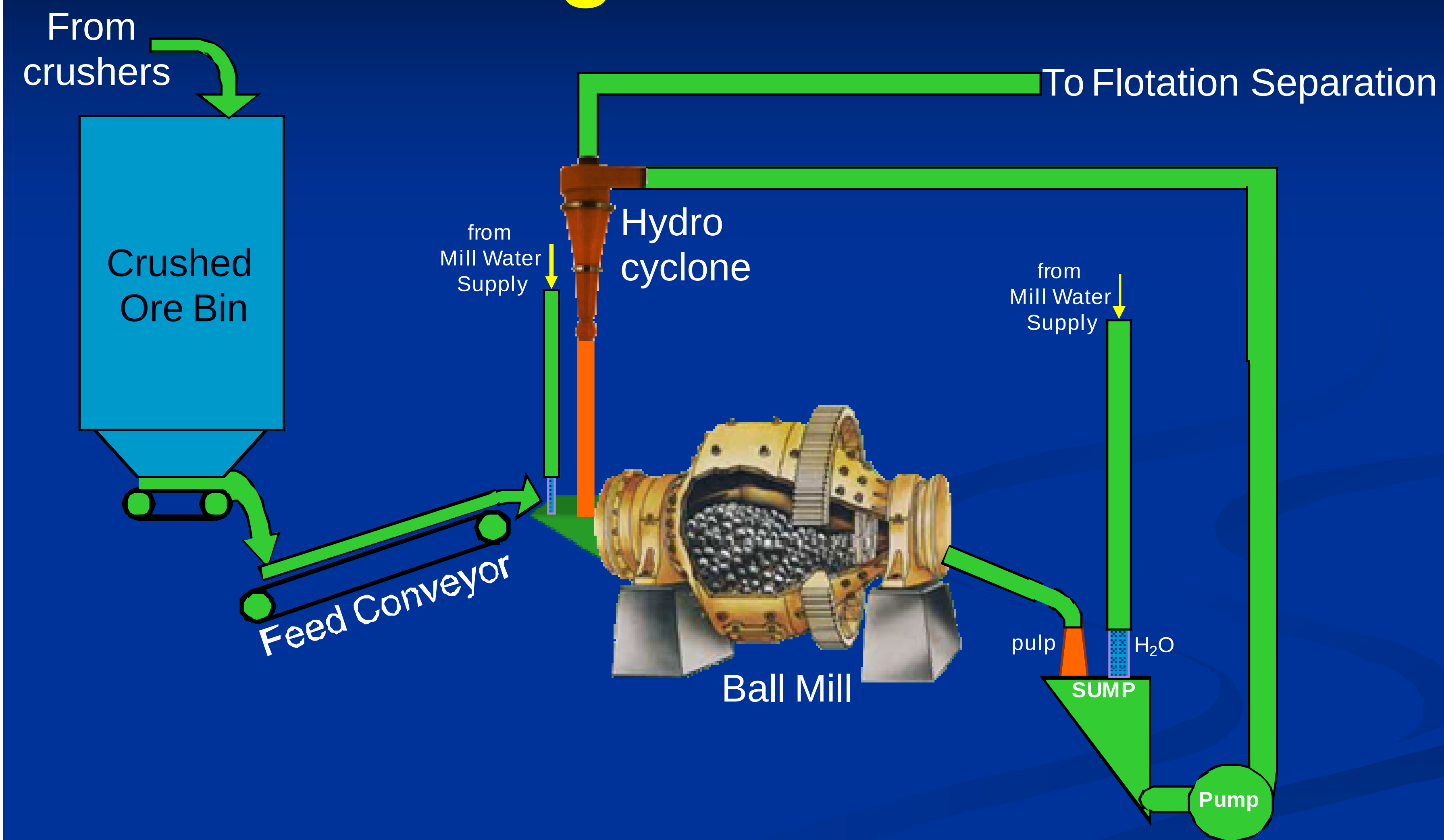
Building a Flowsheet - 6



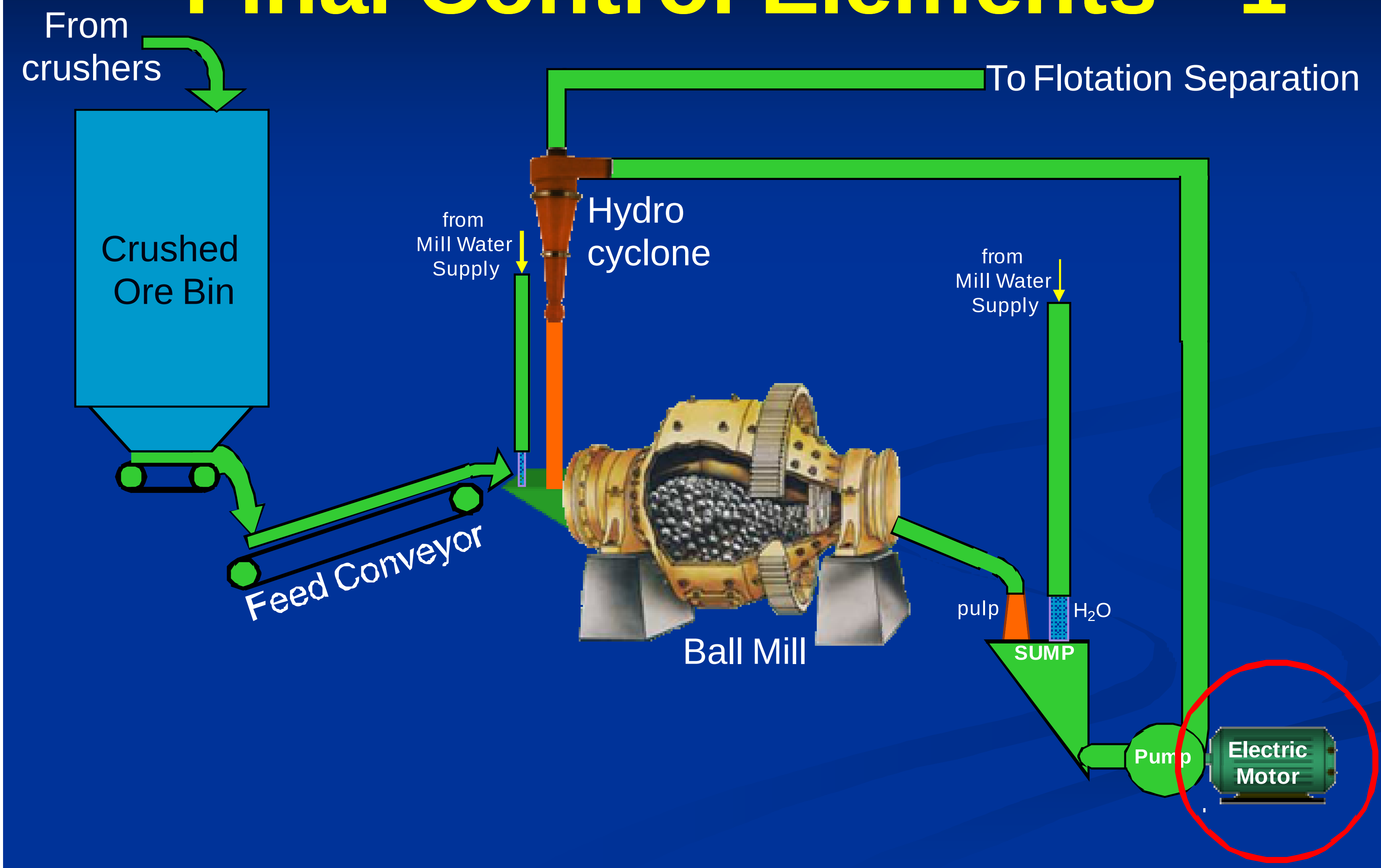
Building a Flowsheet - 7



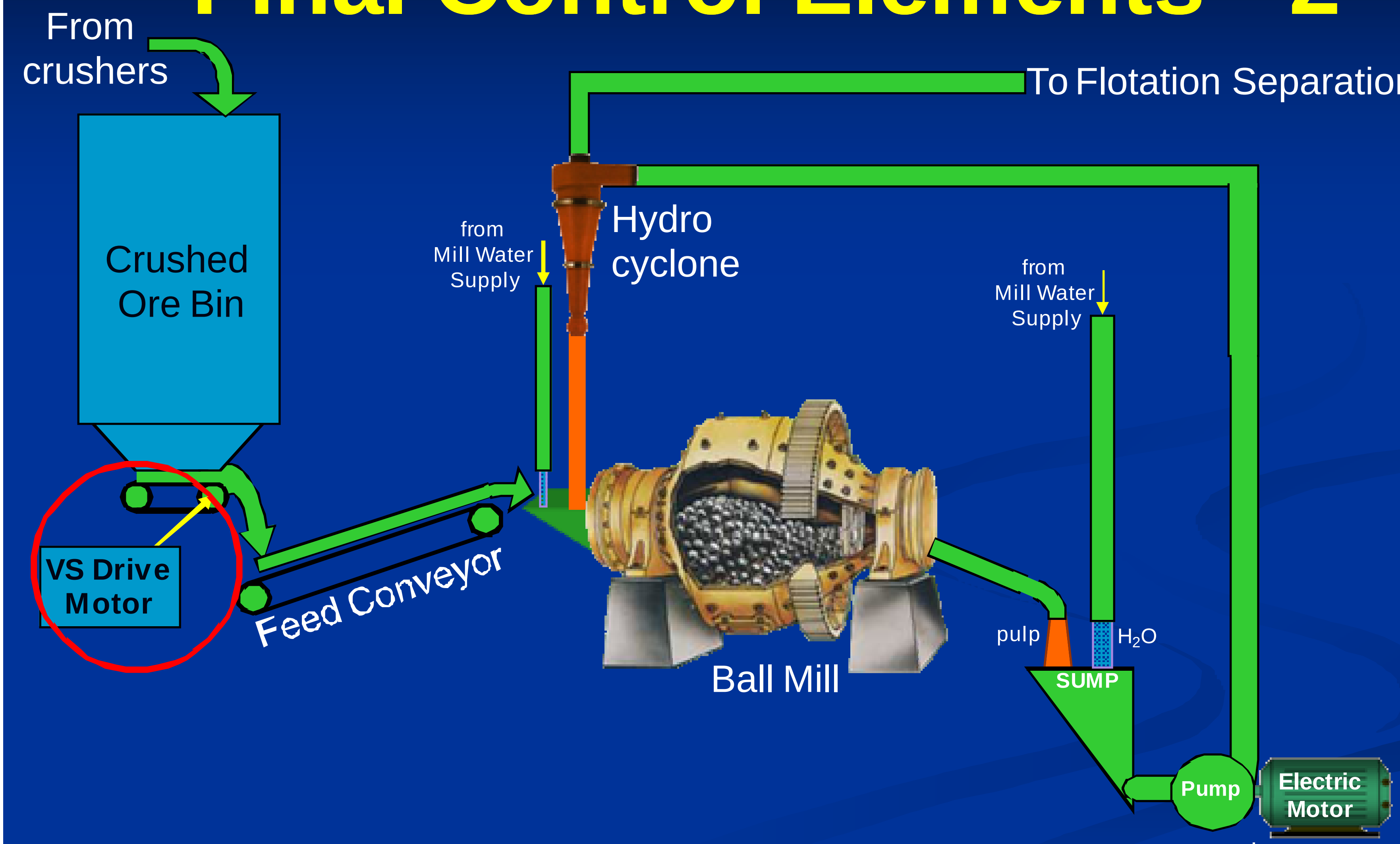
Building a Flowsheet - 8



Adding Actuators and Final Control Elements - 1

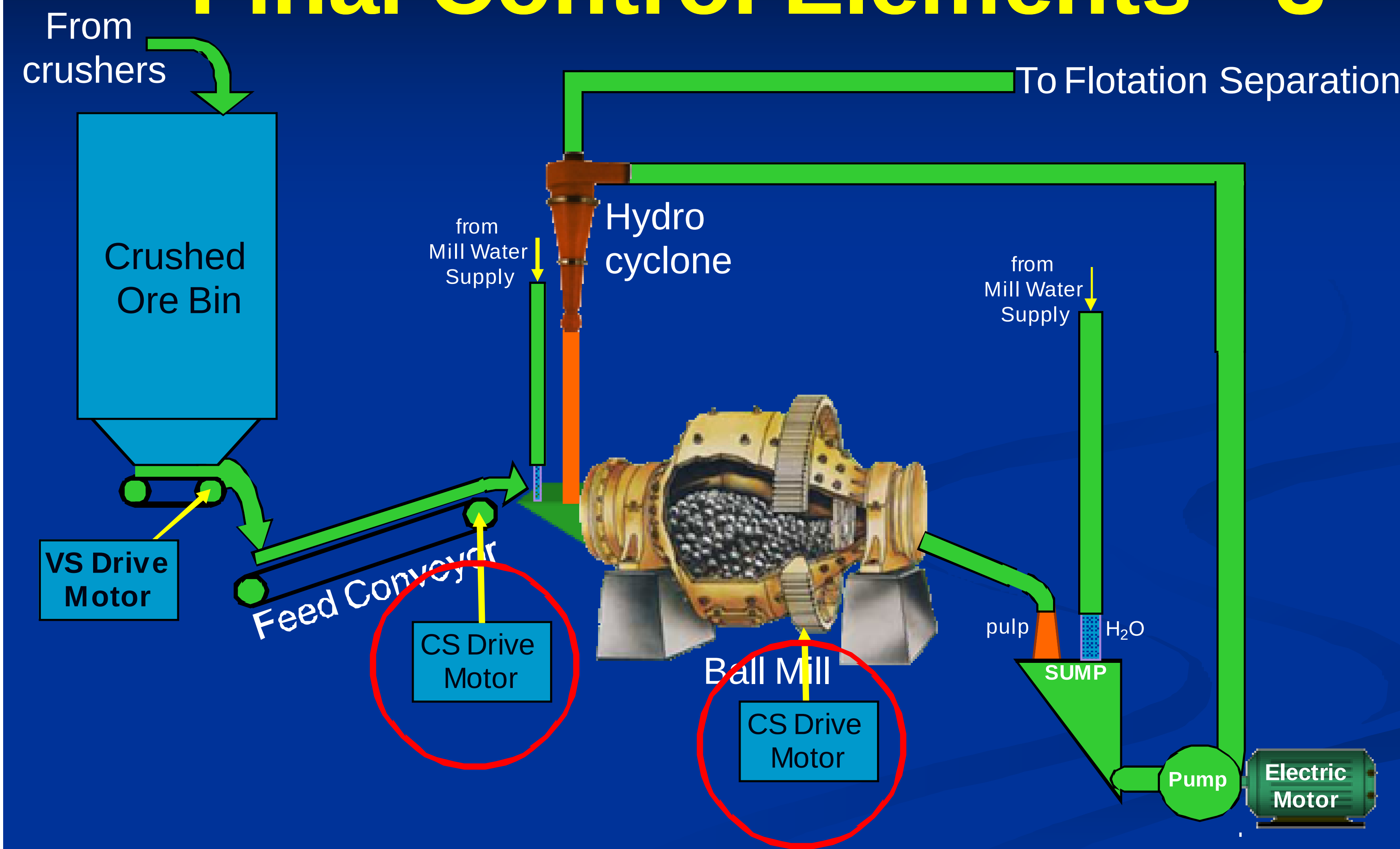


Adding Actuators and Final Control Elements - 2



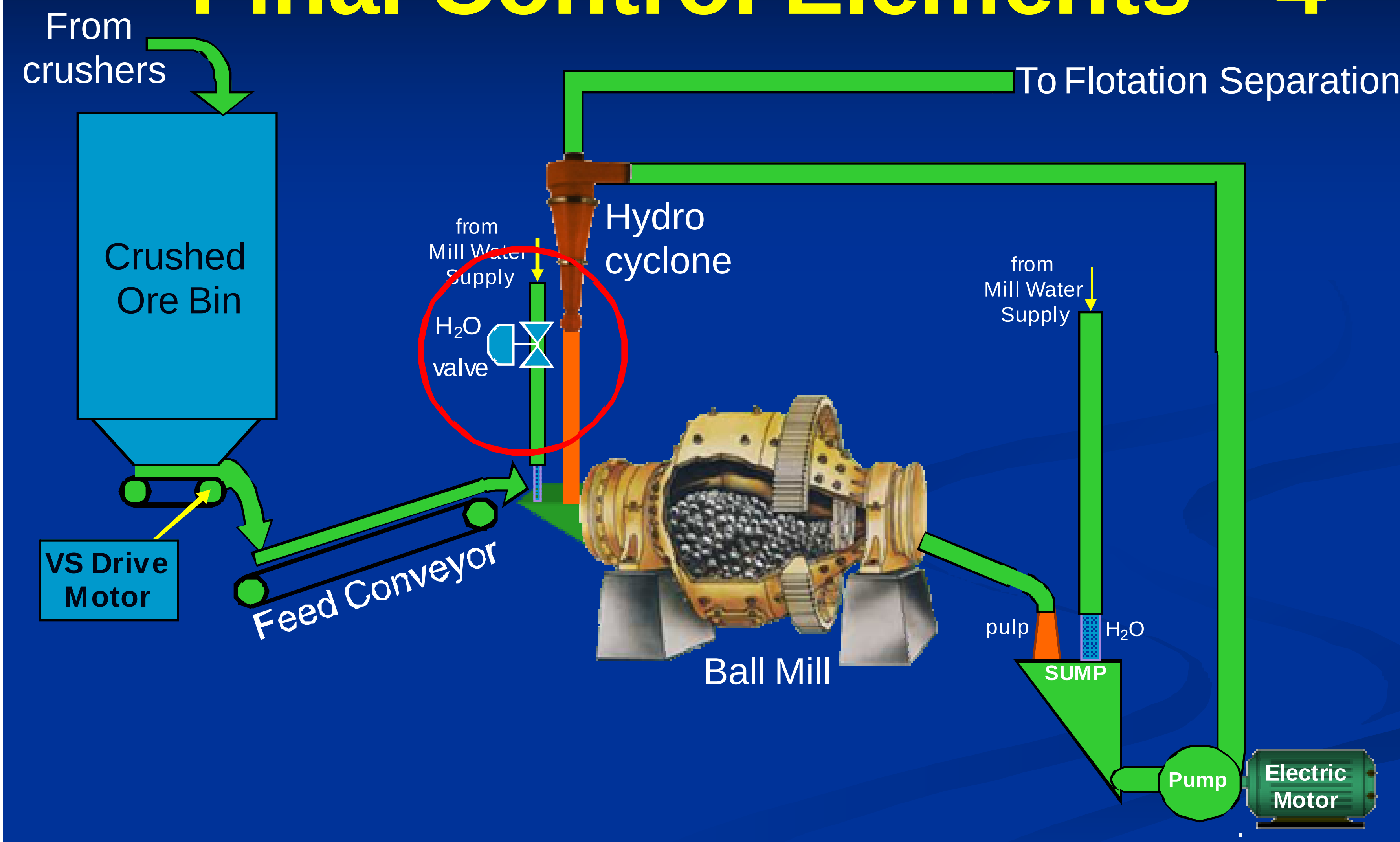
VS = Variable Speed

Adding Actuators and Final Control Elements - 3



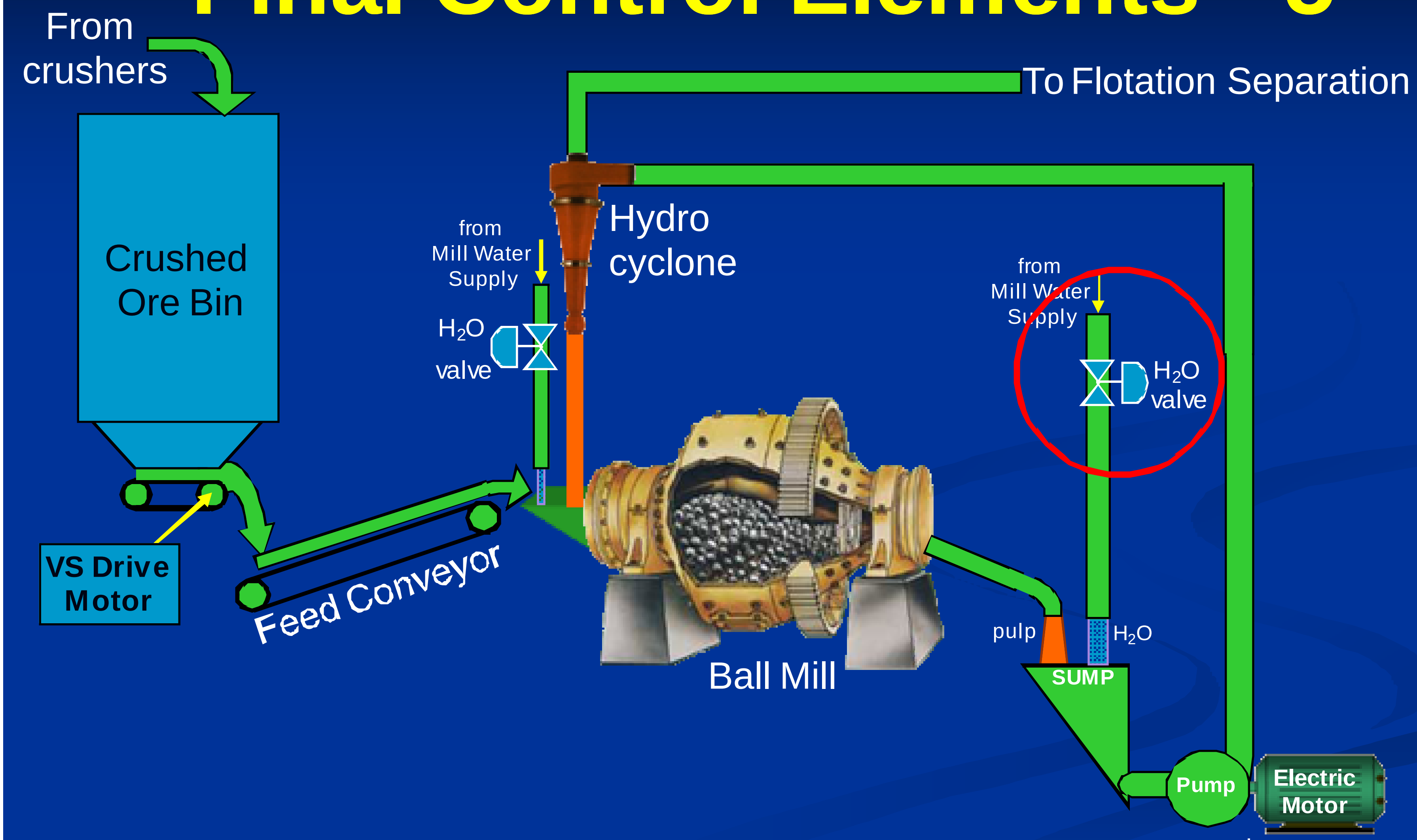
VS = Variable Speed CS = Constant Speed (to be ignored for this exercise)

Adding Actuators and Final Control Elements - 4



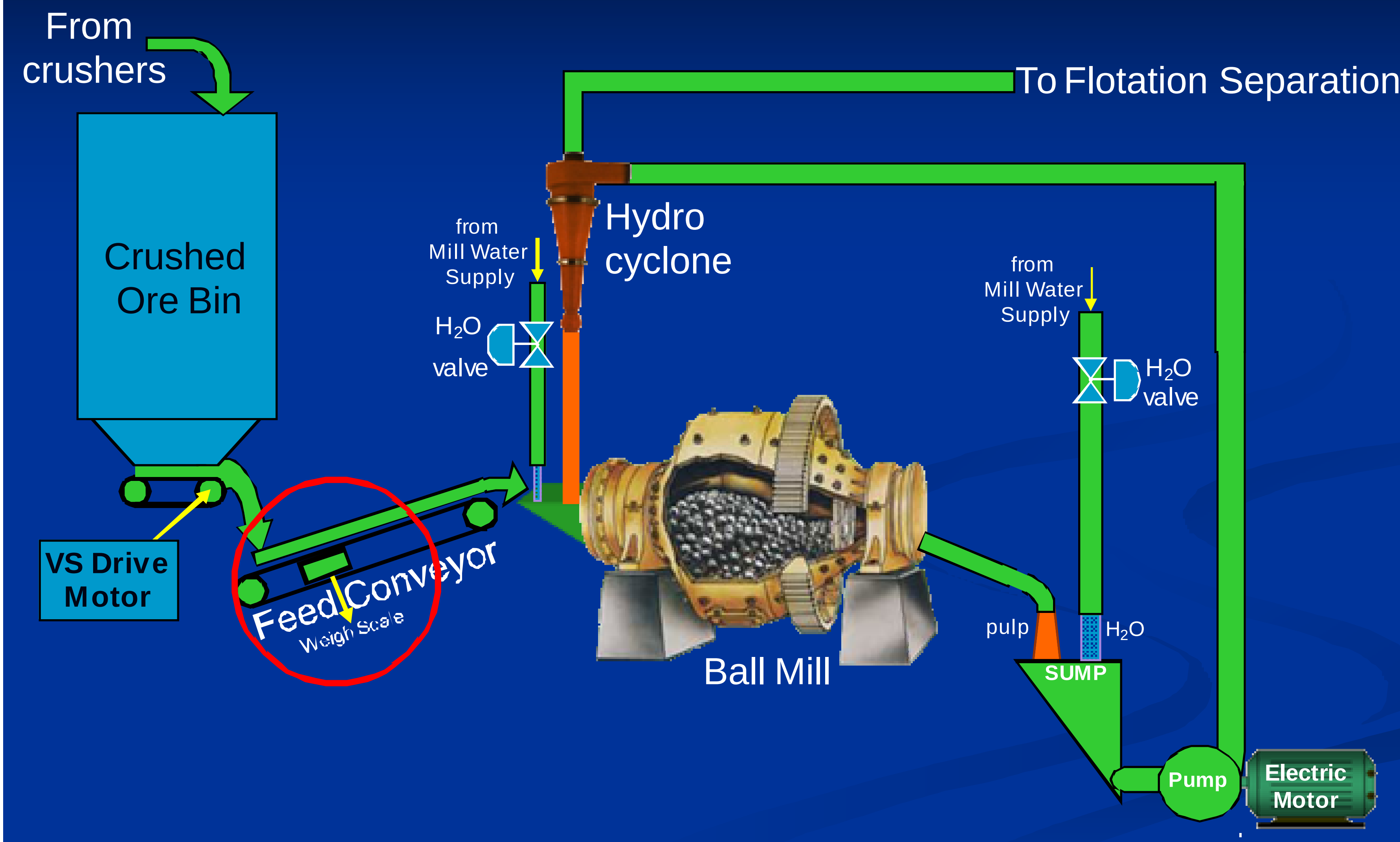
VS = Variable Speed

Adding Actuators and Final Control Elements - 5



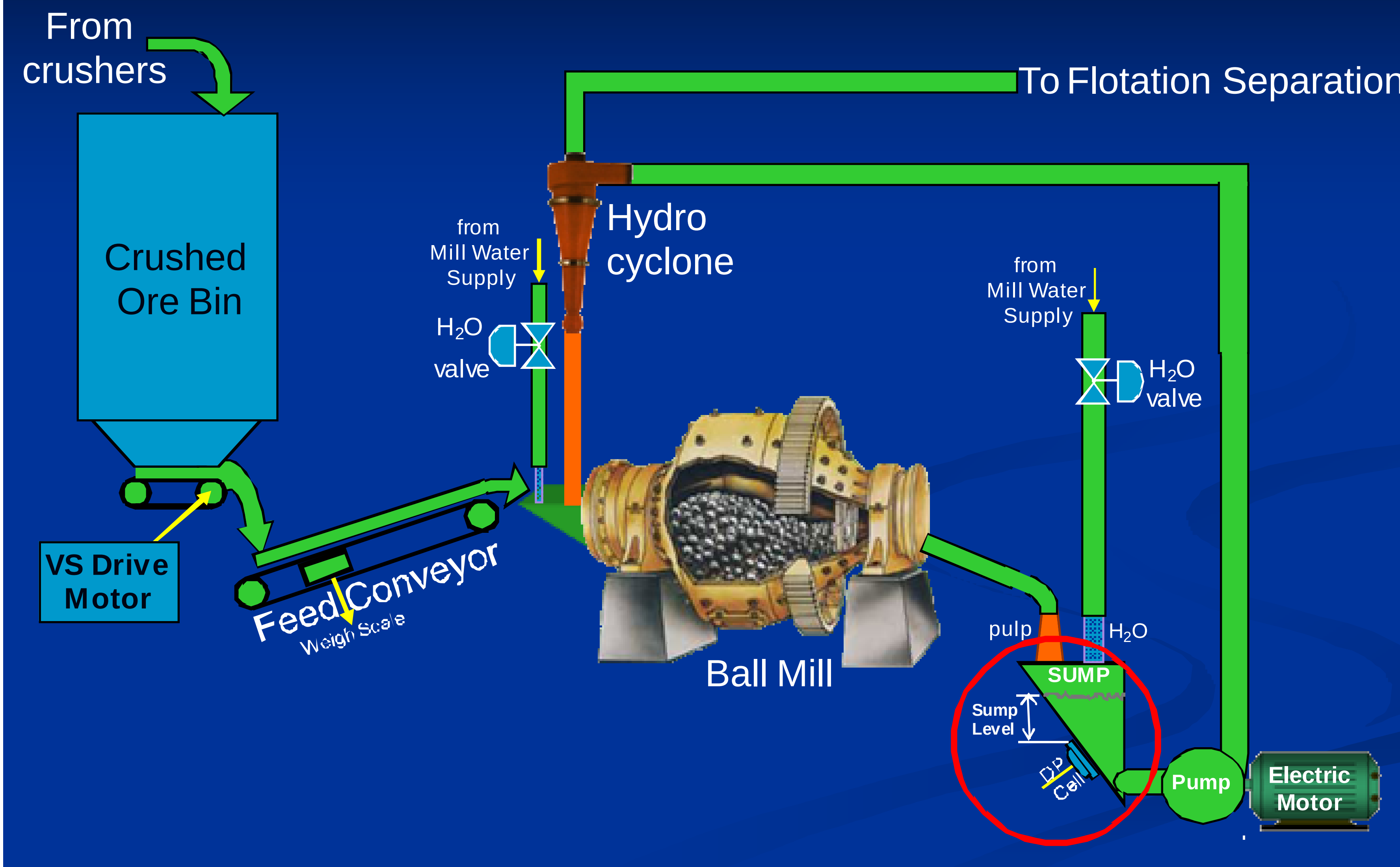
VS = Variable Speed

Adding Instrumentation - 1



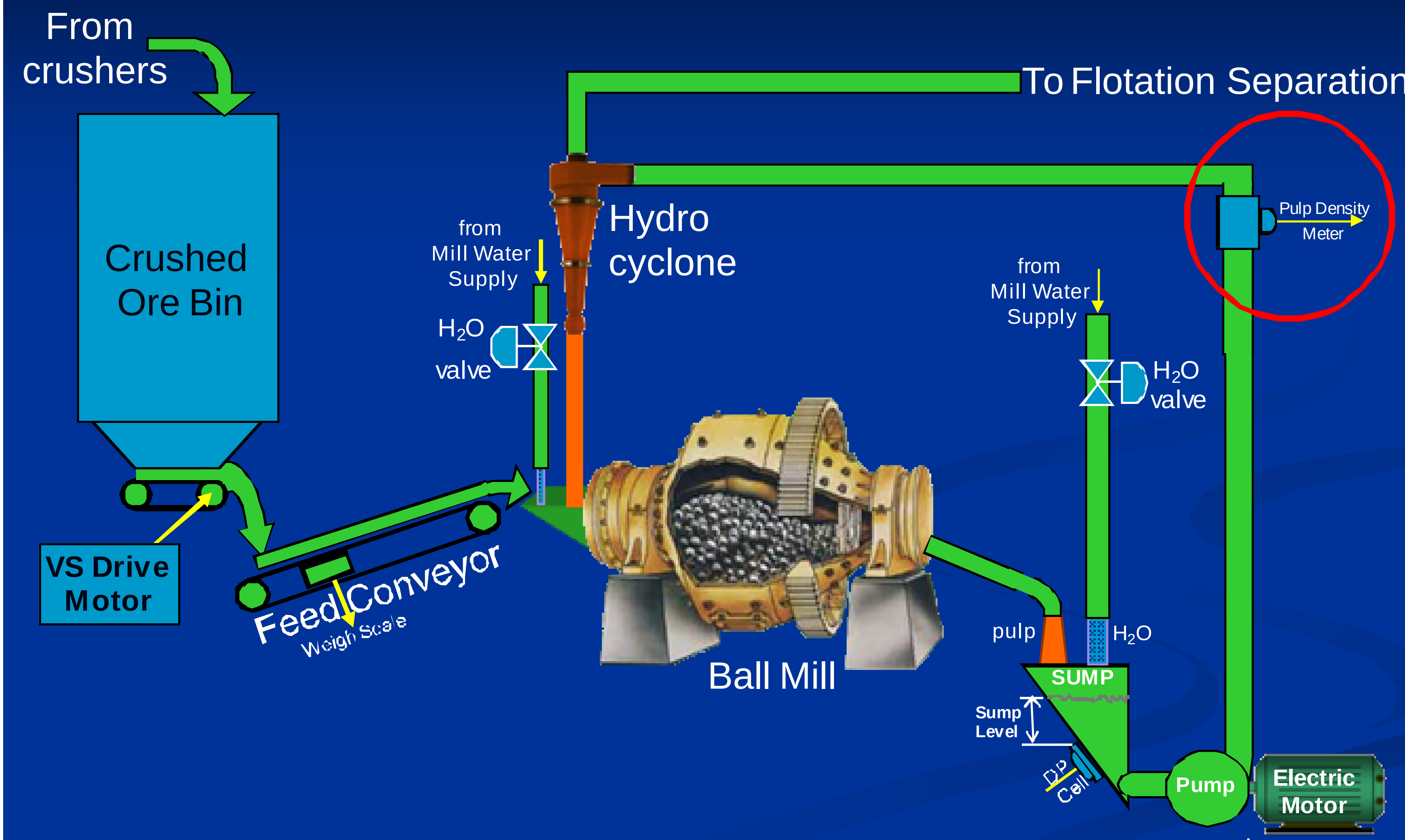
VS = Variable Speed

Adding Instrumentation - 2



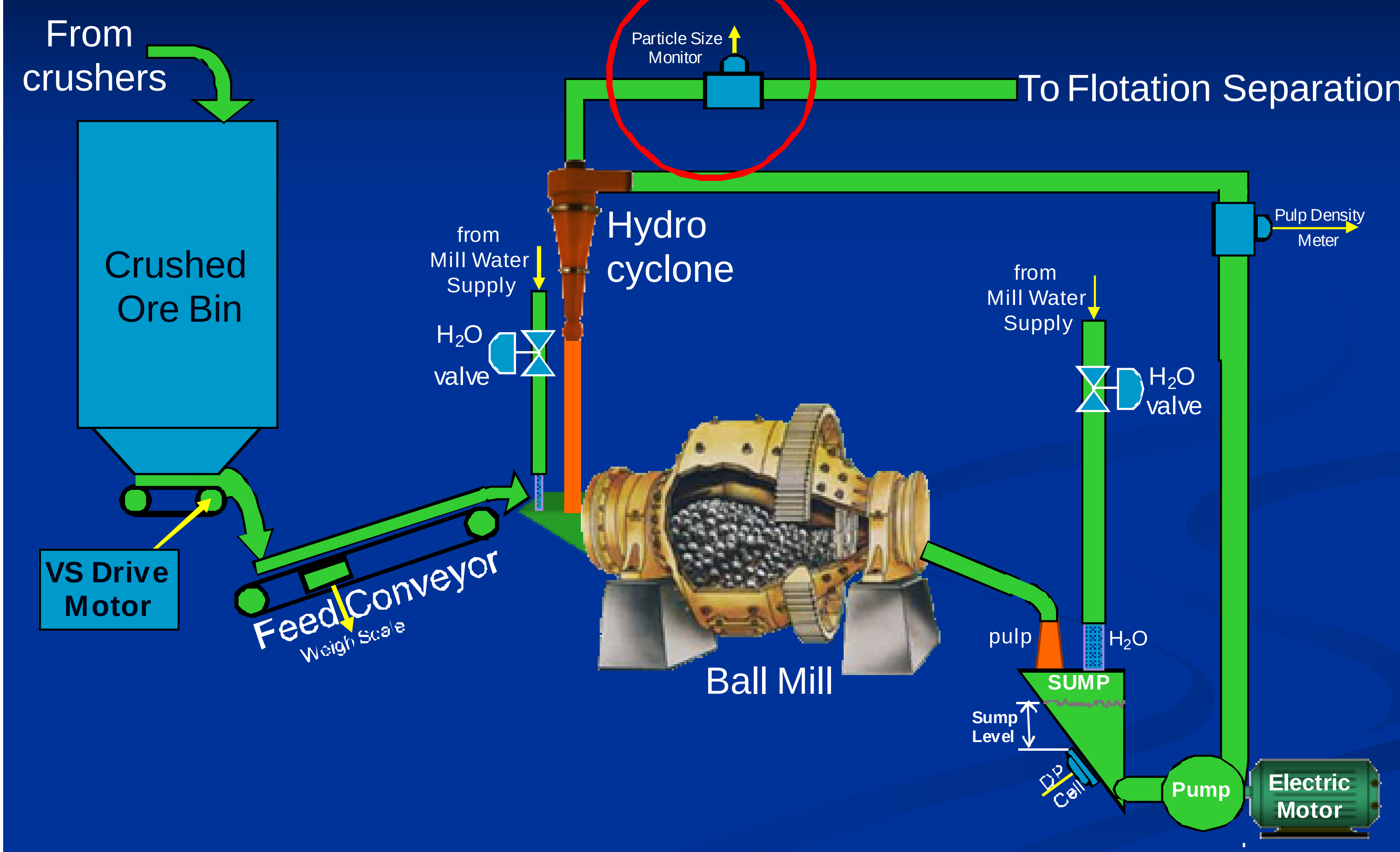
VS = Variable Speed DP = Direct Pressure

Adding Instrumentation - 3



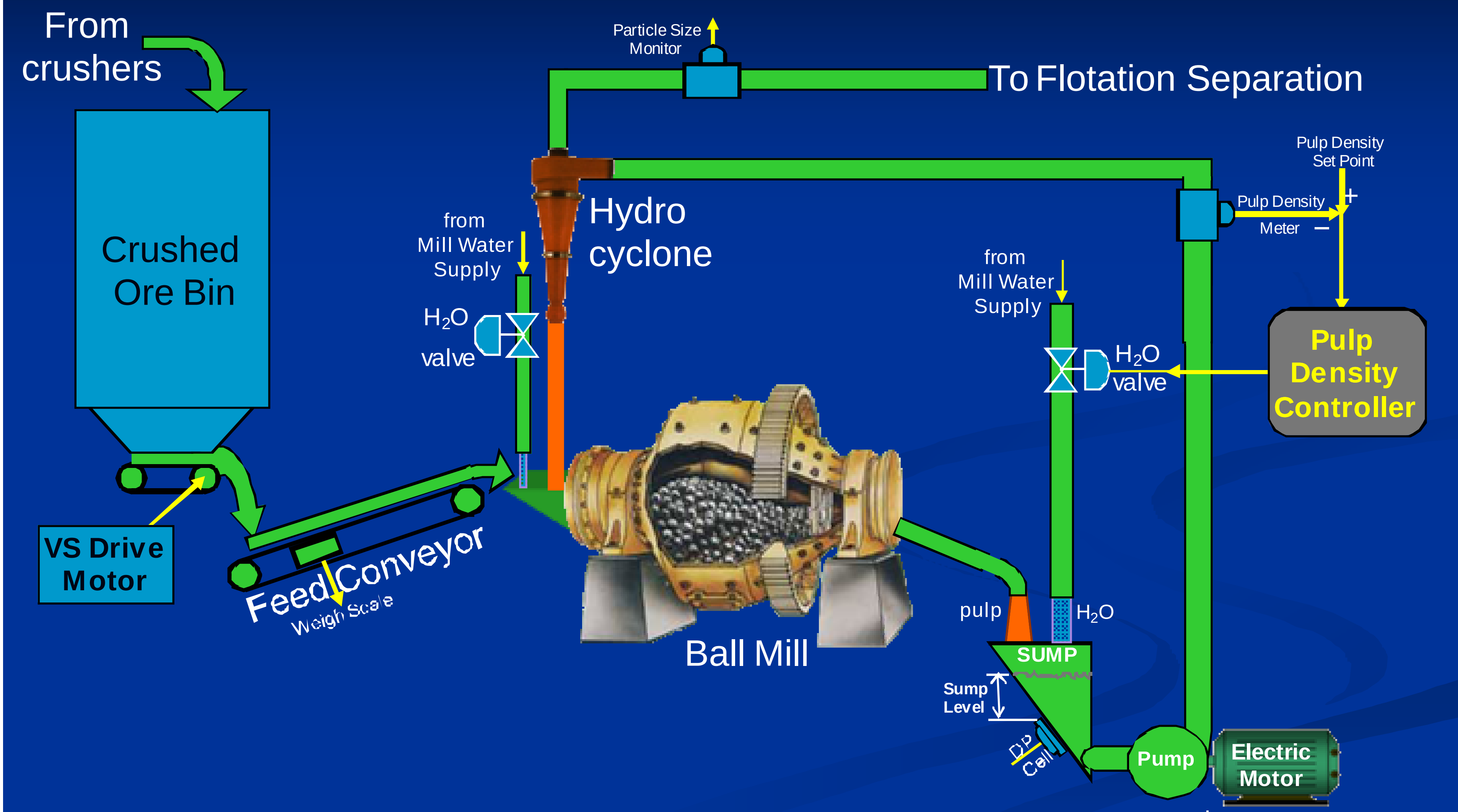
VS = Variable Speed DP = Direct Pressure

Adding Instrumentation - 4



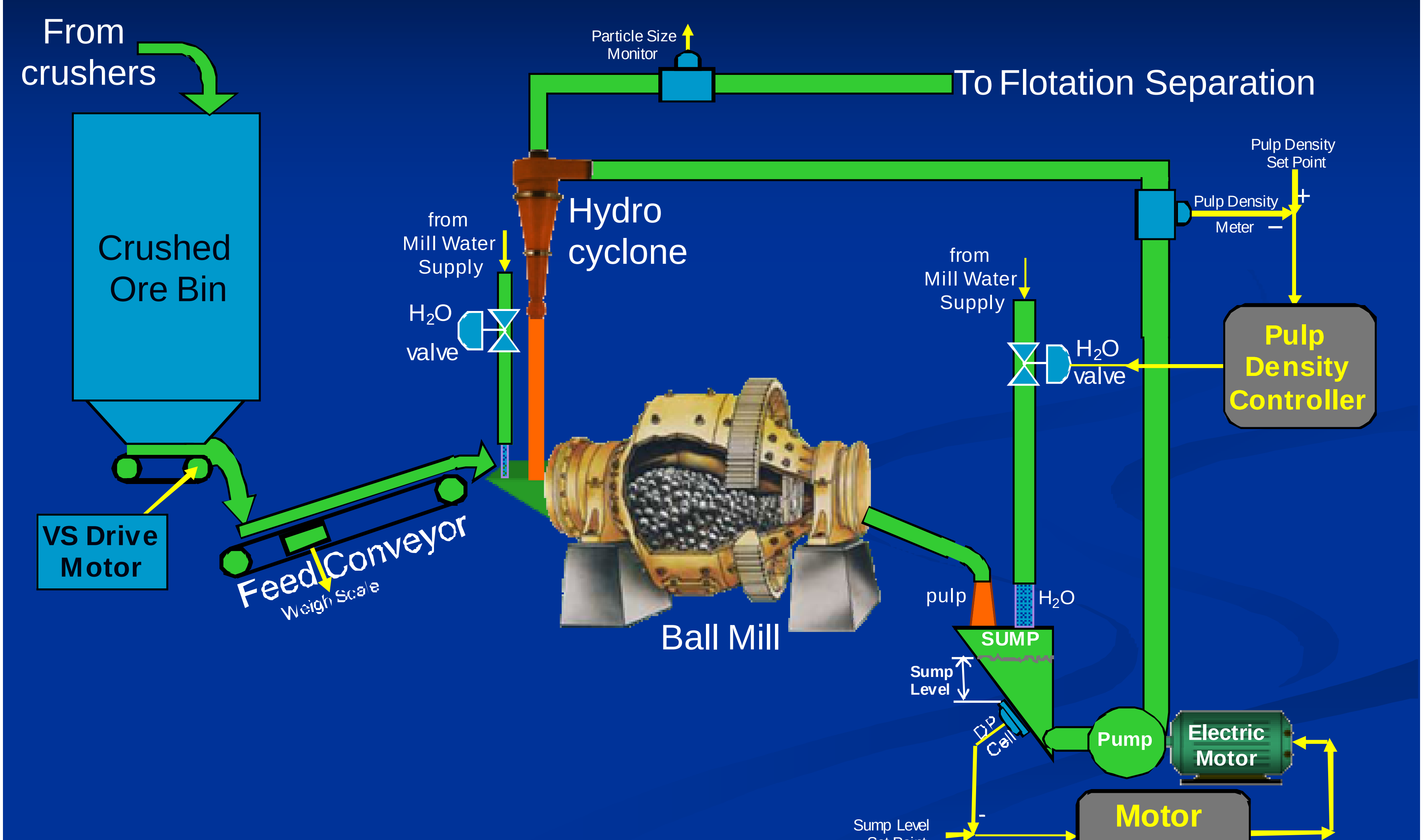
VS = Variable Speed DP = Direct Pressure

Adding Control - 1



VS = Variable Speed DP = Direct Pressure

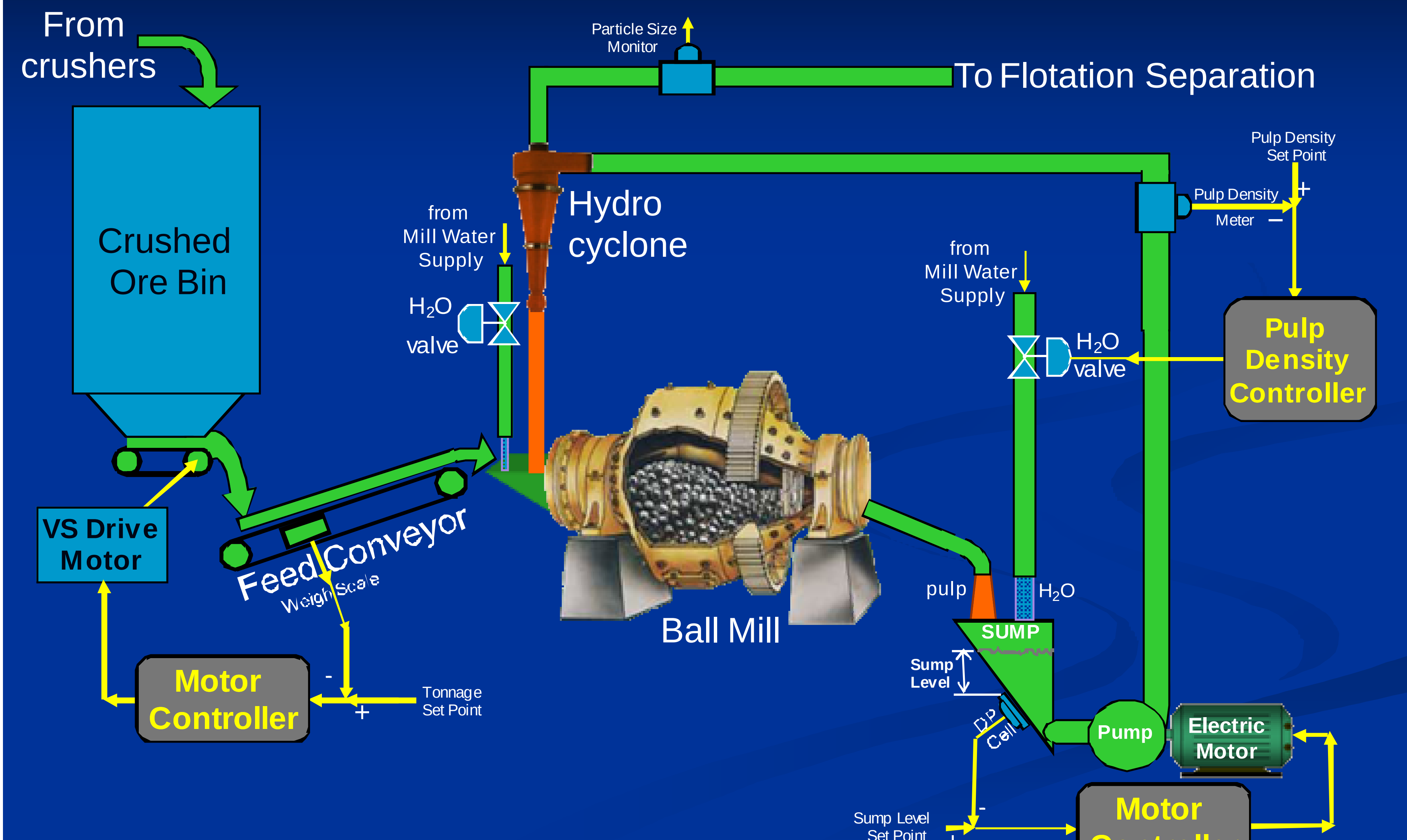
Adding Control - 2



VS = Variable Speed

DP = Direct Pressure

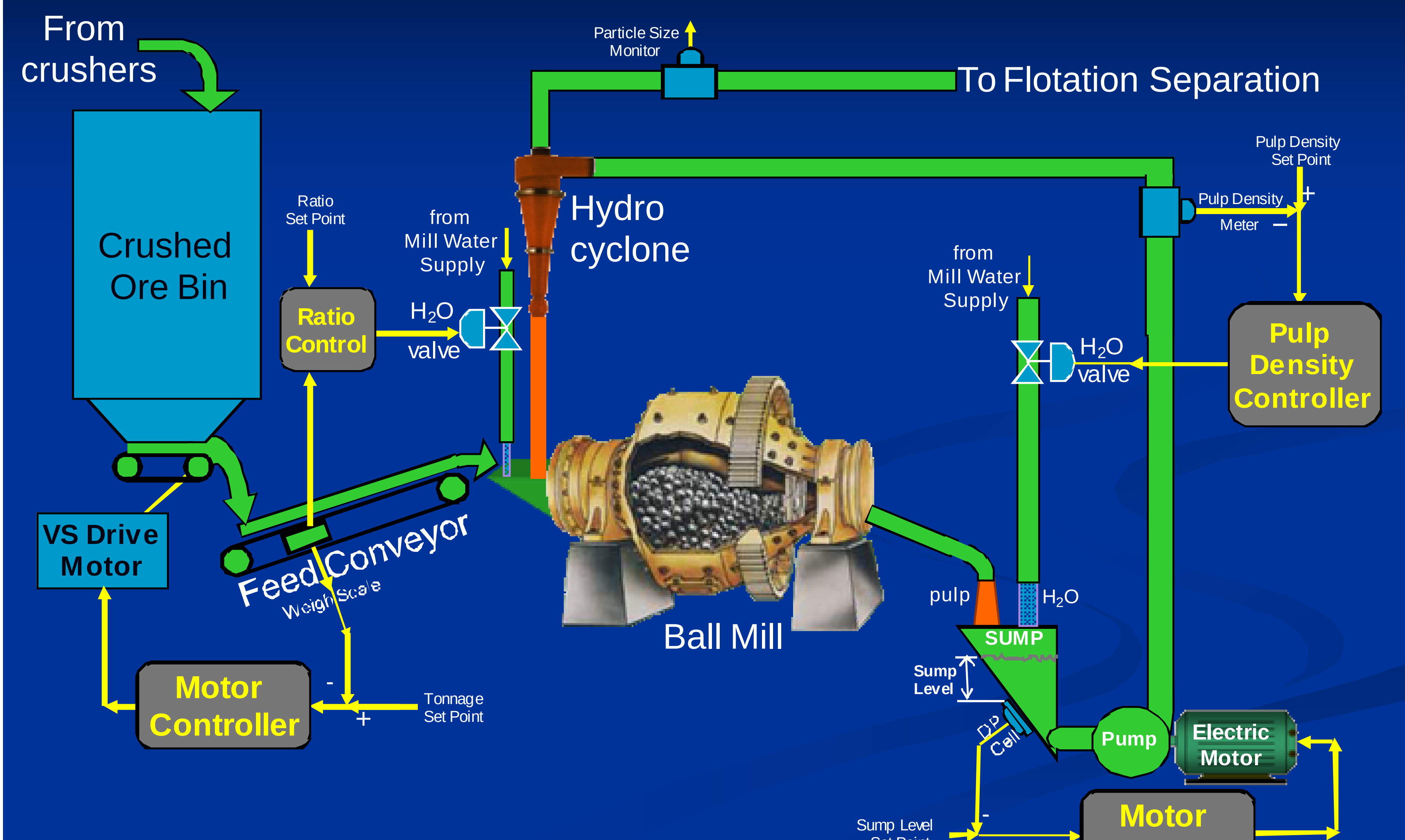
Adding Control - 3



VS = Variable Speed

DP = Direct Pressure

Adding Control - 4



VS = Variable Speed

DP = Direct Pressure

Supervisory Control

Control Goal: Either:	1. Maximize Tonnage Rate	or	2. Particle Size Control
Constraints:	Coarsest "grind" Pulp density (min & max) Sump level (min & max)		Minimum tonnage rate Pulp density (min & max) Sump level (min & max)

In some types of grinding circuits, ball mill power draw may be an important constraint and may require consideration in control of tonnage rate, but in this case, power draw is dominated by the charge of steel balls in the mill.

System Responses

Regulatory Loads

- Ore Feed Hardness changes
- Ore Feed Particle Size Distribution changes
- Water flowrate upsets
- Ball charge wear rate changes (small effect)

Servo Requirements

- Flotation Circuit constraint changes
- Ore Availability changes
- Maintenance (scheduled/unplanned)

Example Strategy – maximize tonnage

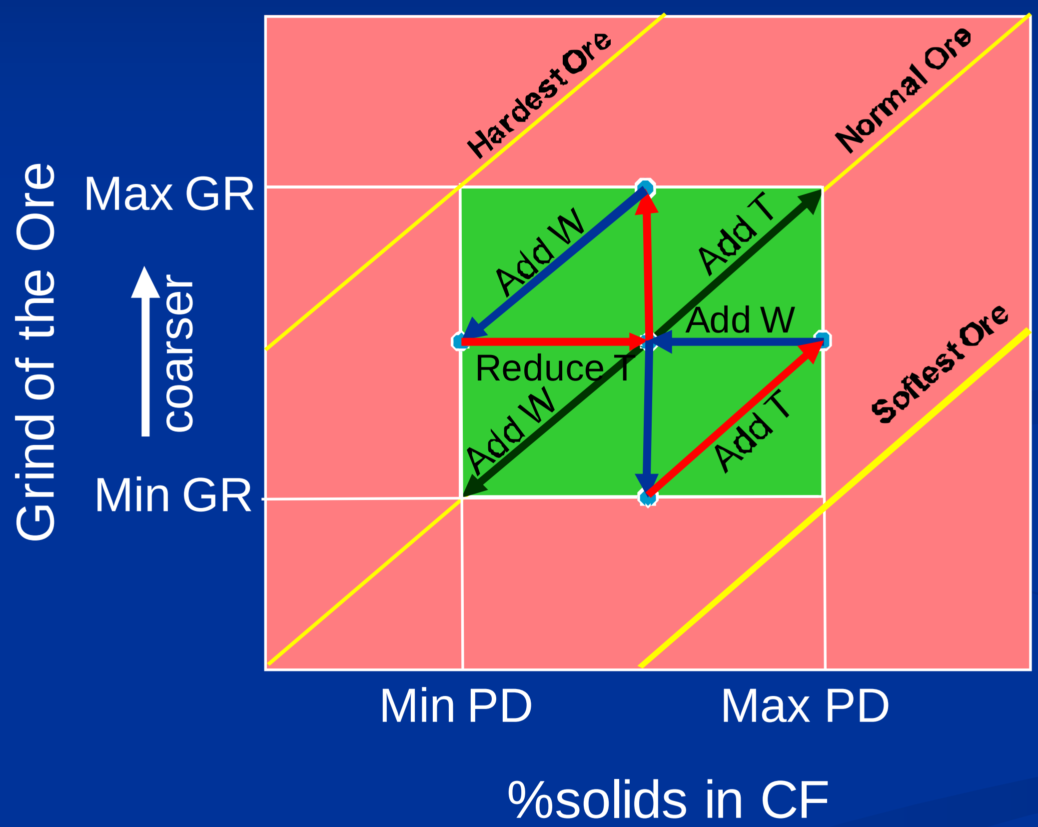
- Maintain particle size (“grind”) by changing pulp density of cyclone feed (CF)
- If “grind” is too fine, then use tonnage rate changes to control grind and set CF pulp density to maximum
- If “grind” is too coarse, then use CF pulp density changes to control grind and set tonnage rate to minimum

Example Strategy – control “Grind”

- Adjust particle size set point to suit ore needs
- Control “grind” using CF pulp density changes
- Maintain constant tonnage until “grind” reaches maximum, then reduce tonnage rate
- If grind becomes too fine, then increase tonnage rate to suit ore conditions

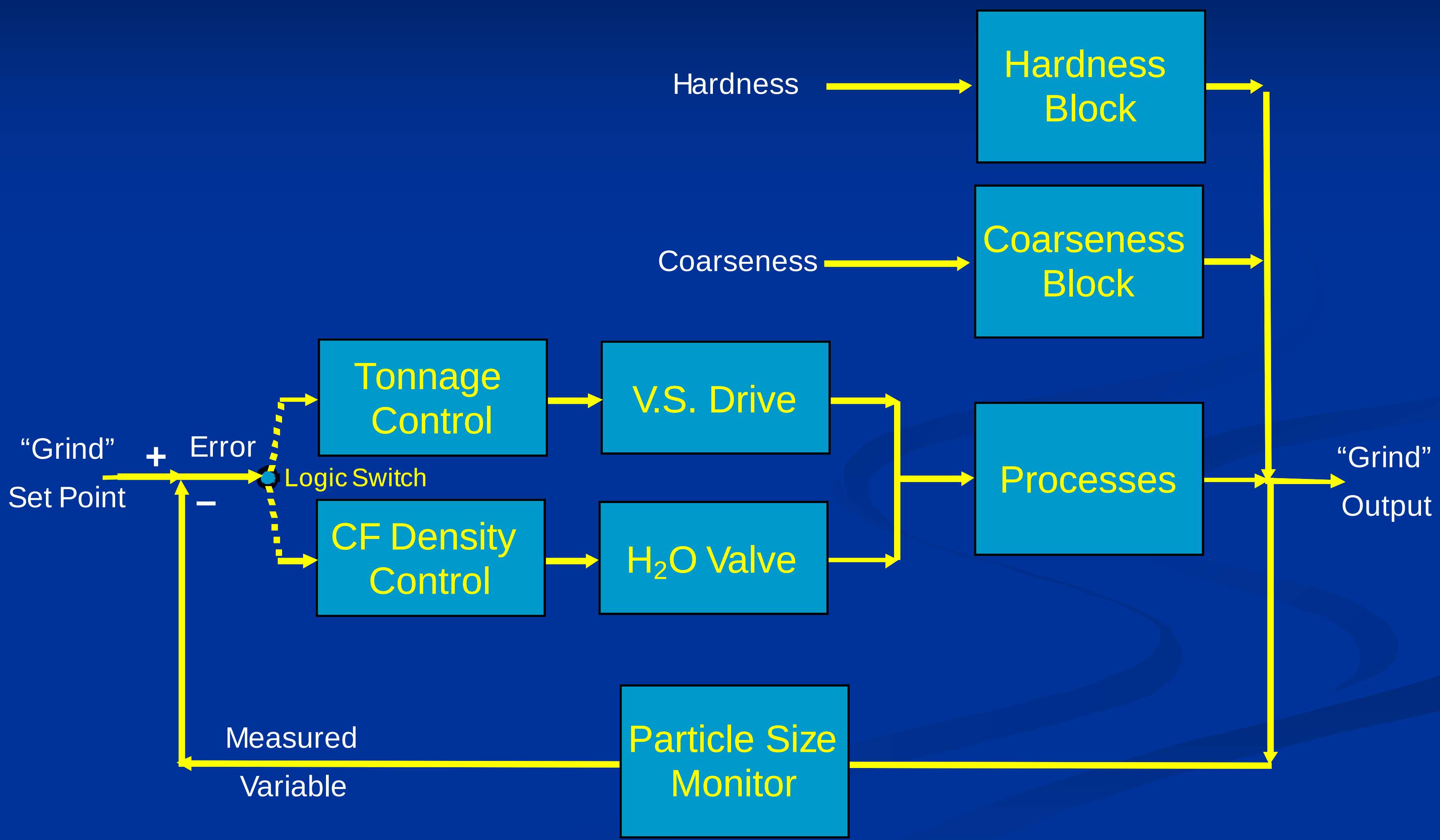
Control of tonnage and water addition

GR = "Grind" PD = Pulp Density

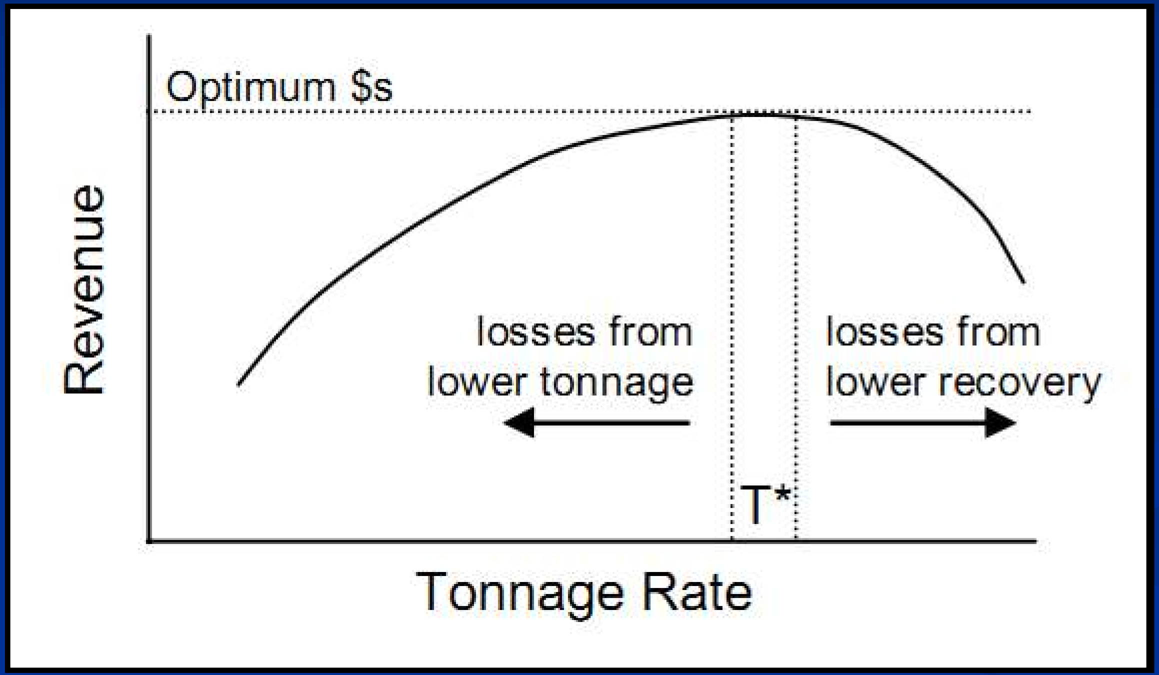


T = tonnage W = Water

Programmable Logic Control

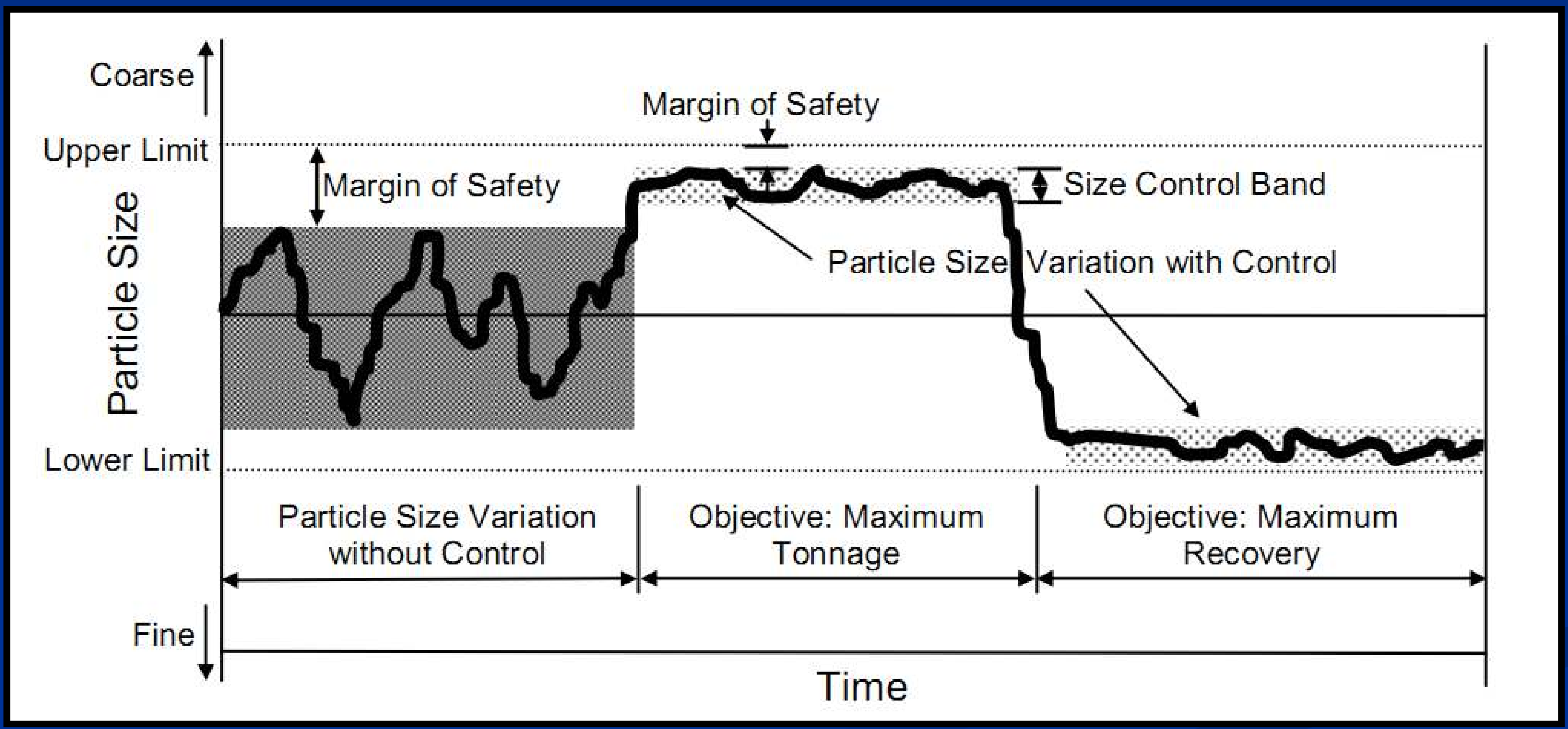


Benefits of Optimizing Tonnage Control



- %Recovery drops at high tonnage rates because:
  - Ore "Grind" is too coarse – unliberated values are lost to tailings
  - Residence time in Separation Circuit is too short

Advantage of “Grind” Control

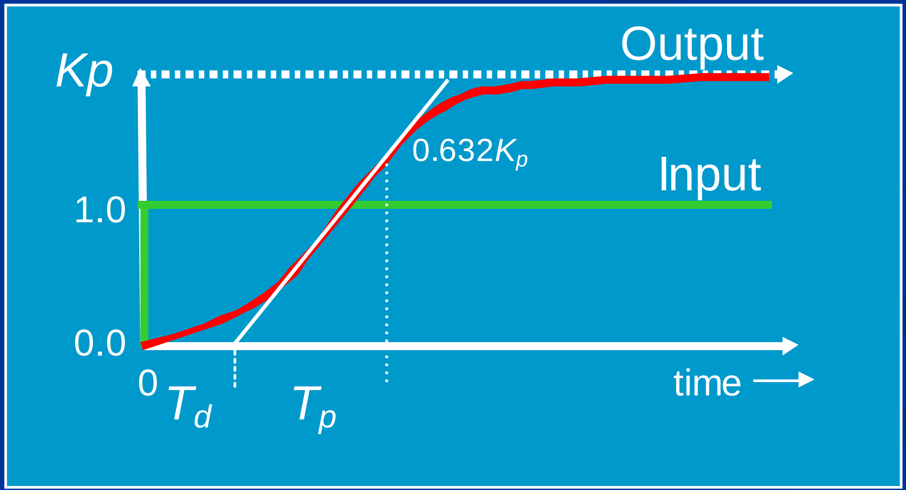


Steps in Designing for Control

- Identify and categorize all variables
  - Design variables that will not change
  - Variables that can be measured and changed
  - Variables that can be measured, but not changed
  - Variables that cannot be measured, but inferred
  - Variables that cannot be measured or inferred
- Which are Inputs, Outputs, and Loads
- Choose a goal for the system
  - Select targets or set points for the outputs
  - Decide what is to be maximized or minimized

Steps in Designing for Control

- Perform system identification testwork
  - Study the open-loop system response between one input variable and one output
  - Characterize process delays (T_d) and lags (T_p)
  - Characterize process gains (K_p)



Steps in Designing for Control

- Choose type of controller
  - Proportional (P)
  - Proportional-Integral (PI)
  - Proportional-Integral-Derivative (PID)
  - Do not use Derivative with noisy signals
- Select controller constants (tuning) to provide slightly underdamped response
  - K_c
  - T_i
  - T_D
- Study effects of interacting control systems

Steps in Designing for Control

- Examine advanced control techniques
  - Cascade control (fast inner loop)
  - Feed-forward control (fast and predictive)
  - Adaptive Control (lags, delays, and gains are not constant)
  - Model-based Control (updating & comparing with process)
  - Advanced Signal Filters (Kalman, Smith predictor, etc.)
  - Intelligent Control (fuzzy, neuro-fuzzy, expert systems, etc.)
- Ensure system is stable under all conditions
- Set-up Alarms to detect non-standard states

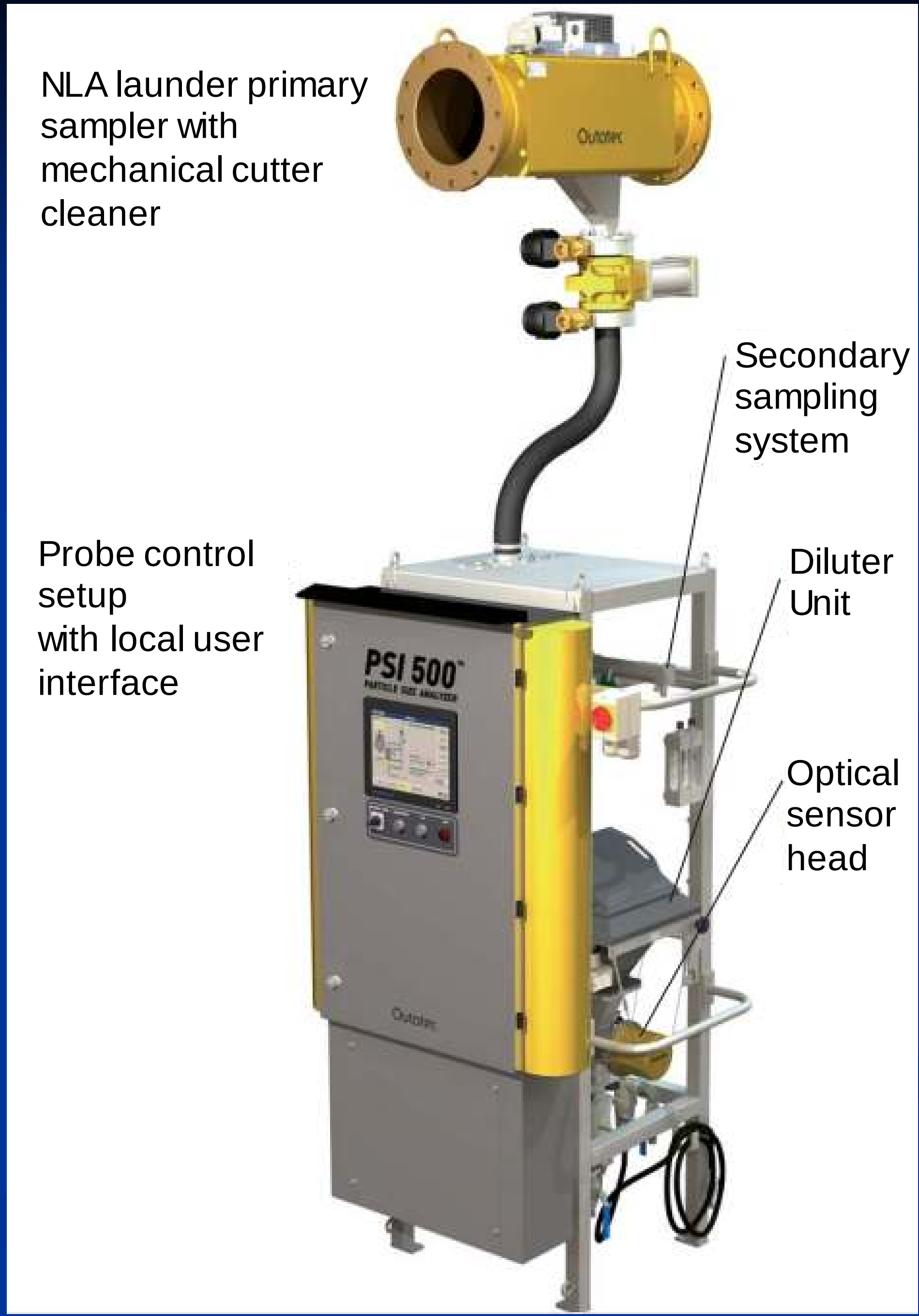
Questions ?

Extra Slides

Outotec's PSI 500 Analyser

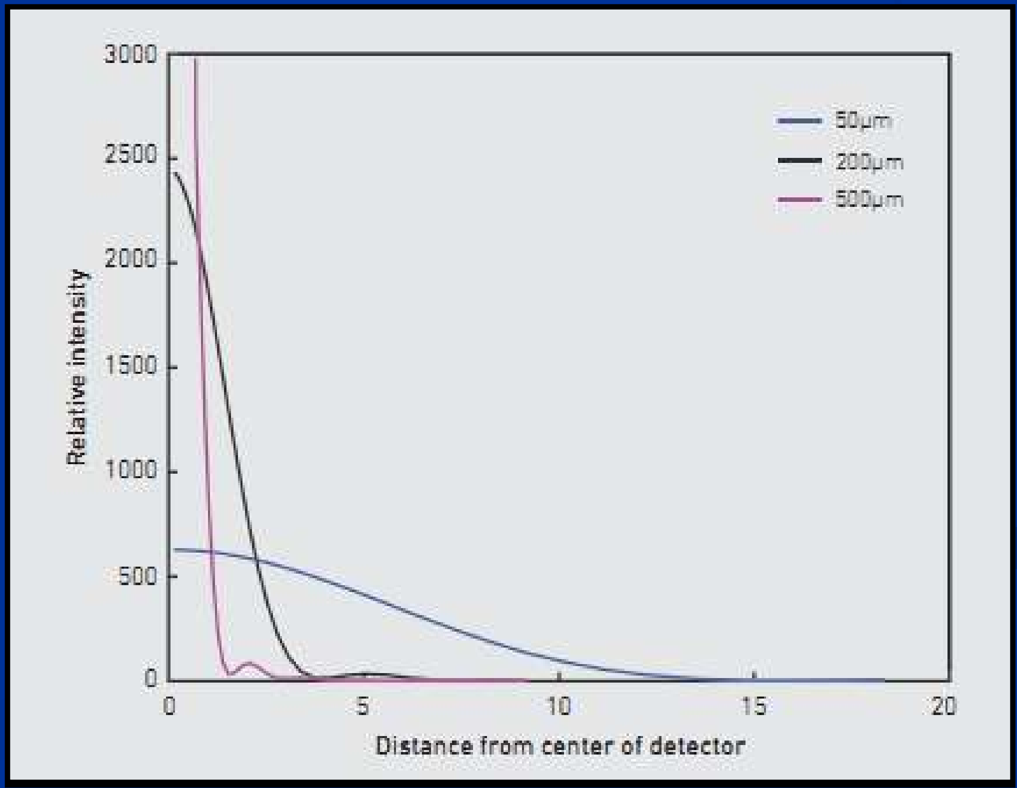
- Particle Size Analysis based on laser diffractometry
- Outputs both PSA and %solids data
- Accuracy = ± 2%
- Can handle particle size distributions as low as 500 mesh (~20 microns)
- Accurate samples are diluted by 10 to 100:1 so laser can penetrate the slurry for measurement

- PSI 500 System with primary sampler
- Easy to use and maintain



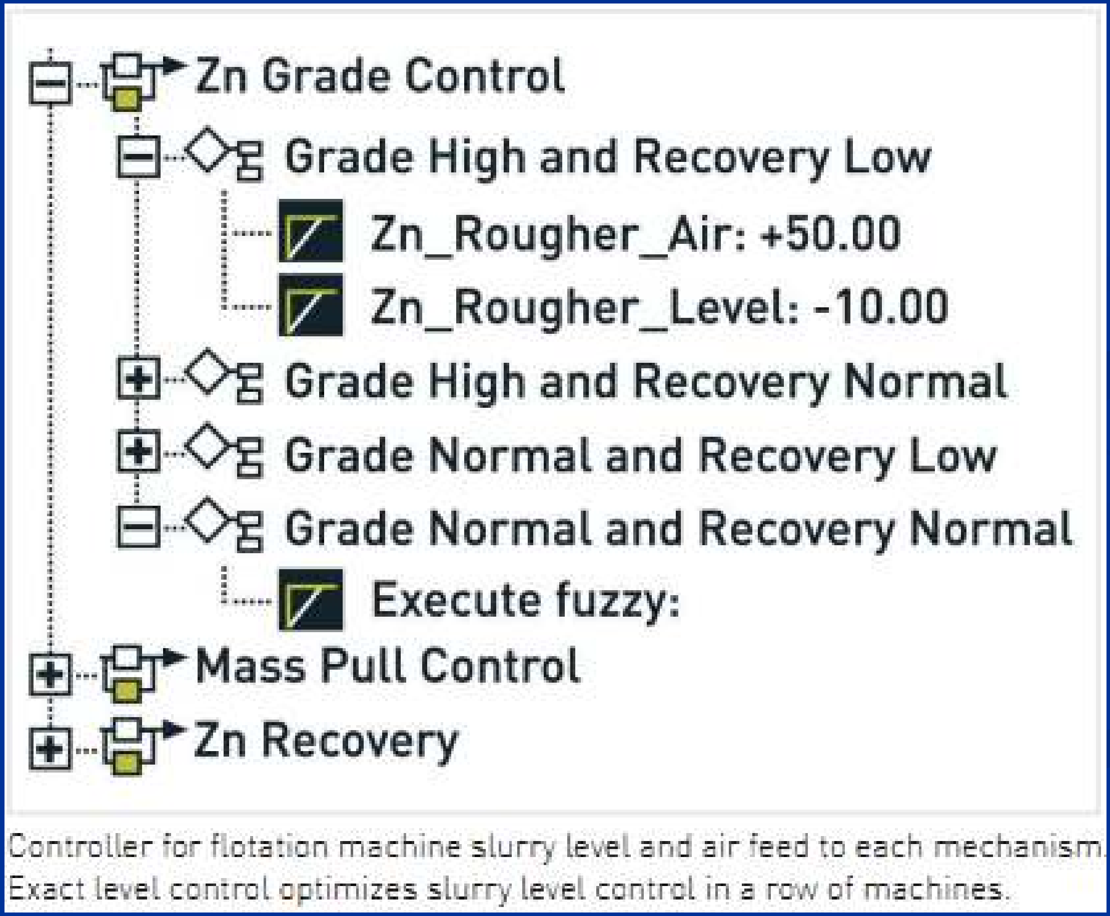
Principles of Laser Diffractometry

- Small particles diffract laser beam light more than coarse particles.
- Diffraction pattern measured by sensor array
- Resulting signals used to calculate particle size distribution.
- A beam power detector measures non-diffracted laser light for dilution control (%solids).
- Lorenz–Mie theory, is an analytical solution of Maxwell's equations for scattering of EM radiation by spherical particles

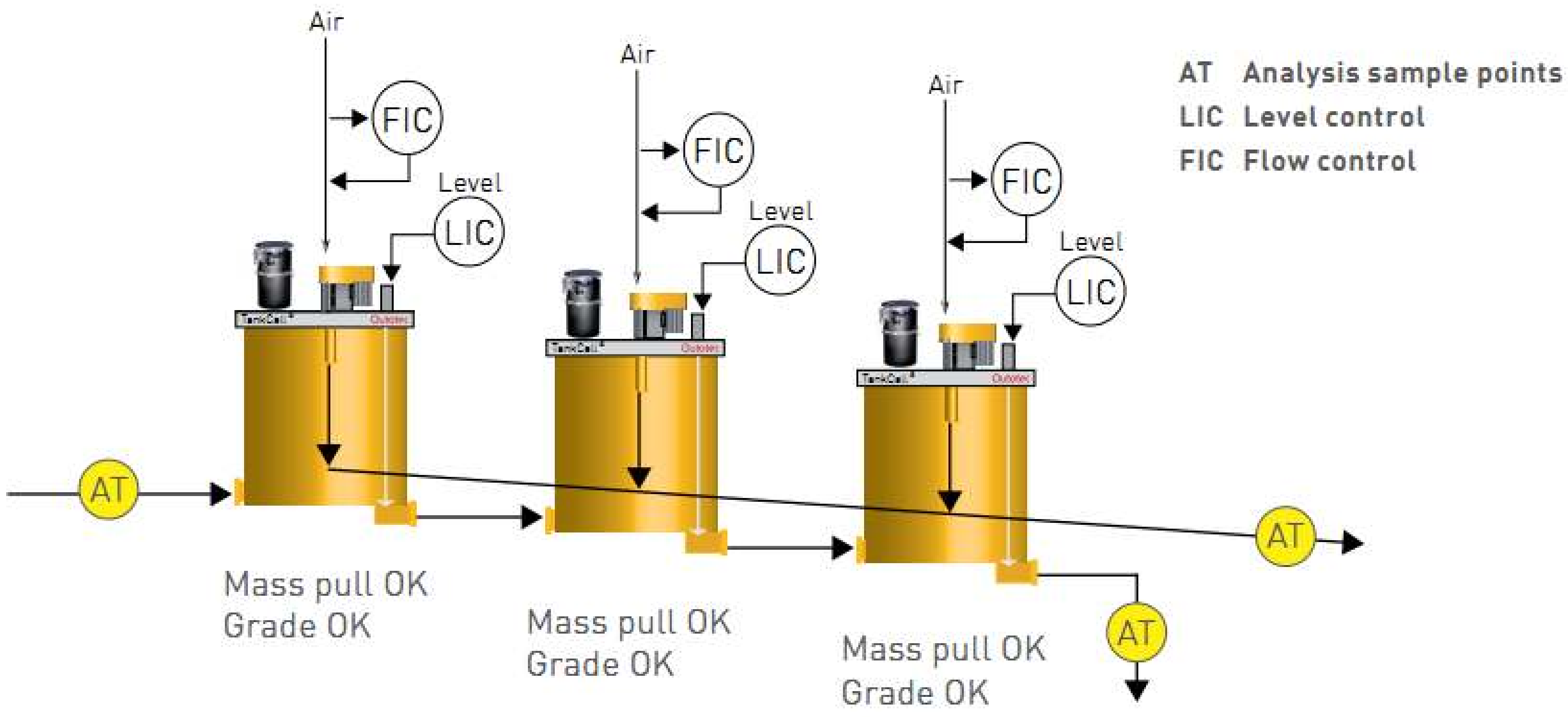


Example of Zn Flotation Fuzzy Control

- Sets up rule maps as below



Control of OK Flotation Cells



The operation of each flotation cell in a rougher row is balanced by froth speed measurements to meet rougher concentrate grade target with best possible recovery.