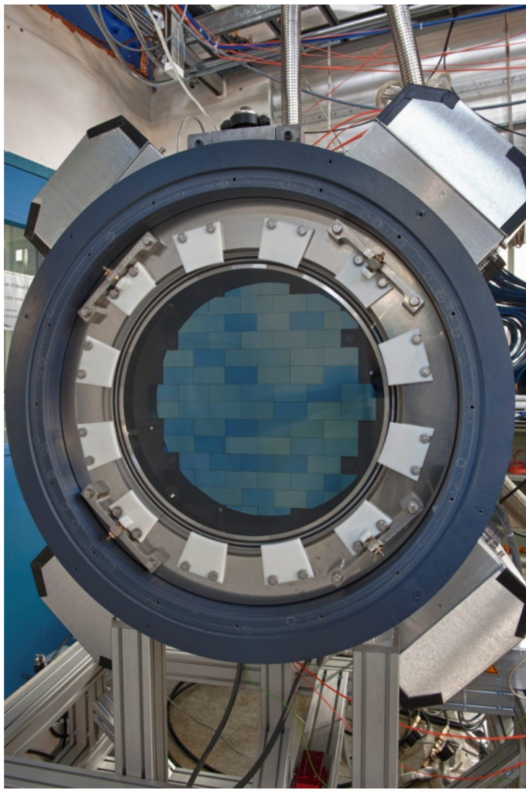
DARK ENERGY
SURVEY

The Design of an Over-Pressure Pump



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DARK ENERGY SURVEY

OUTLINE

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2. OBJECTIVE
3. FUNCTIONAL REQUIREMENTS
4. TYPES OF PUMPS
5. OVER-PRESSURE PUMP
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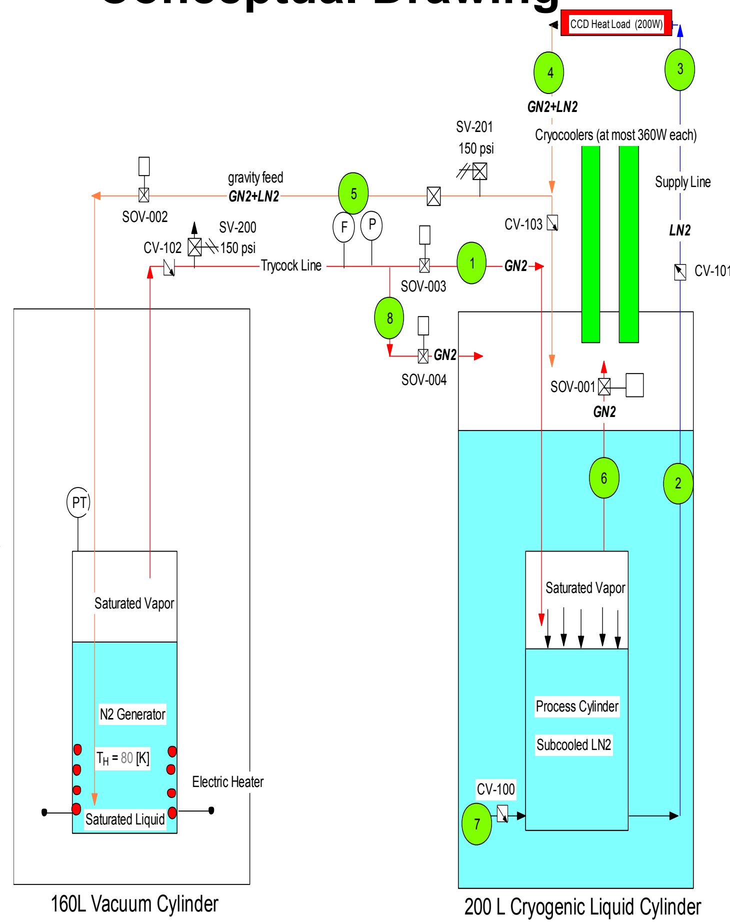
    2. Define System Limits
    3. Pump Theoretical Analysis
6. ADVANTAGES AND DISADVANTAGES
7. PROPOSED RESEARCH METHODOLOGY
    1. Research methods
    2. Design phases
8. CONCLUSION

Conceptual Drawing



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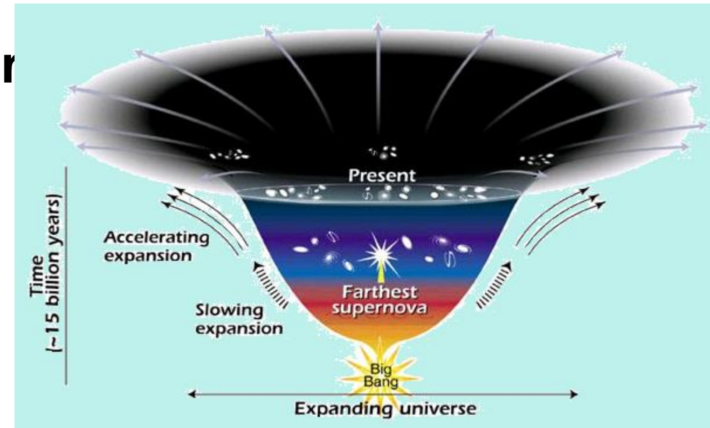
3. INTRODUCTION

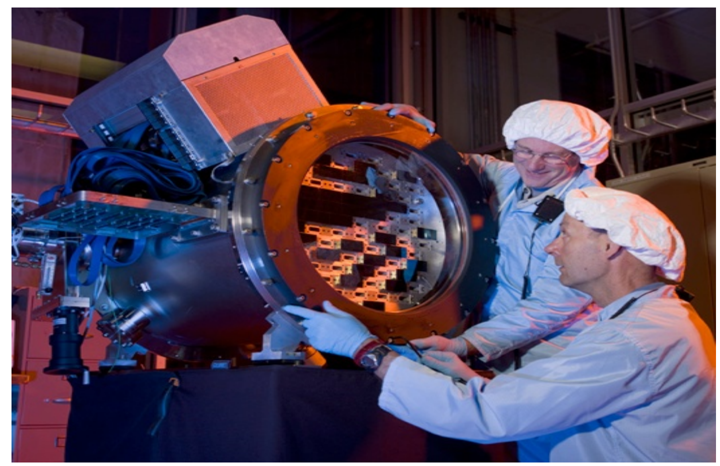
What is Dark Energy?

- **Counteracts the gravitational pull of matter**
- **Reason for the expanding universe**
- **Dark Energy Camera (DECam)**



What is DECam?

- **570 Megapixel camera**
- **8 million pixels per CCD**
- **Cooled to 100K**



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3. INTRODUCTION

What about the DECam cooling system?

- **2-phase flow system**
- **Barber-Nicholas pump breaks down**
- **Closed loop**
- **Cryocoolers- condenses GN2**

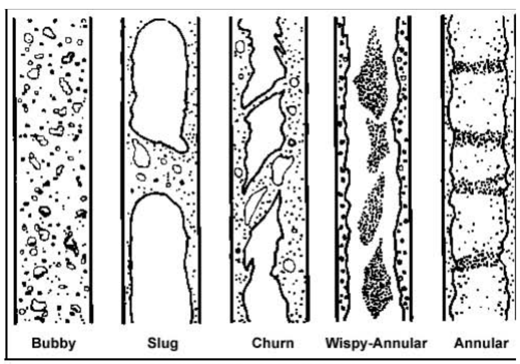

Figure 12.1. Two-phase flow patterns in vertical upflow.

1. OBJECTIVE

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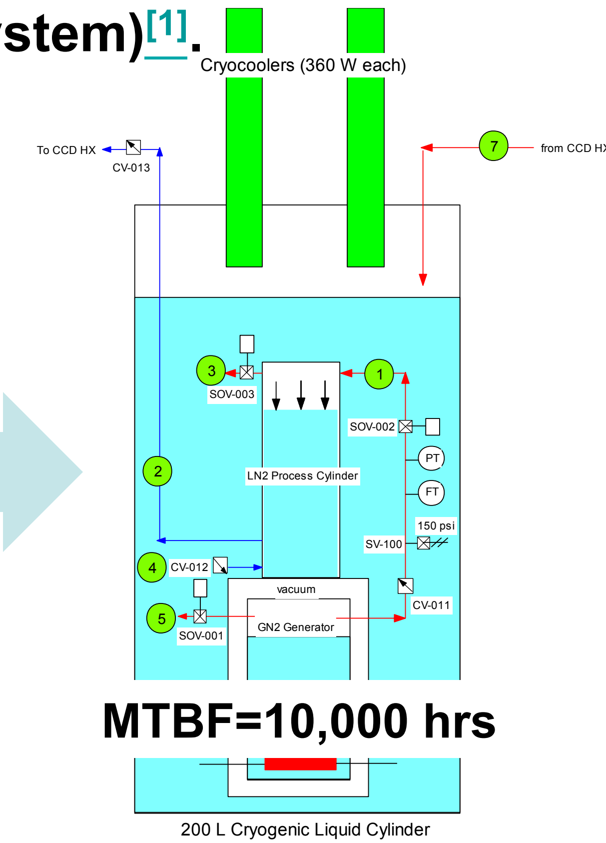
To design a pump that will replace the Barber-Nichols centrifugal pump for the Dark Energy Camera (DECAM) imager cooling system (LN2 Cooling System)[1].



MTBF=10,000 hrs

[1] M... to Failure: ~1000 hrs

2. FUNCTIONAL REQUIREMENTS

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Required flow rate:	2gpm	0.1262 liters/s
Pump head:	~20 psi	137.895 kPa
Maximum cooling capacity for a cryocooler:	0.3412 Btu/s	360 W

- **Low maintenance**
- **High reliability**
- **High efficiency**
- **Must be closed loop**

4. TYPES OF PUMPS

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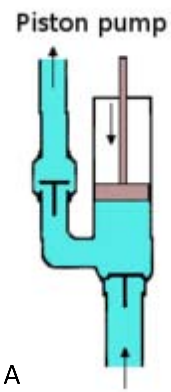
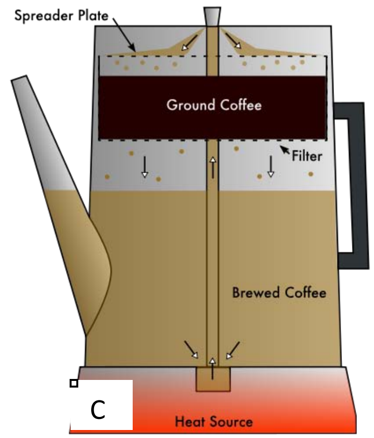


A

B



C

D

E

What do they currently use to cool CCD's?

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QUESTIONS?

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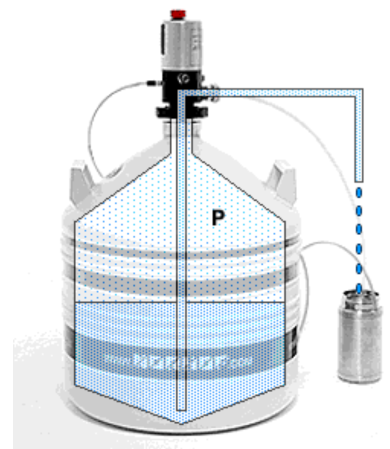
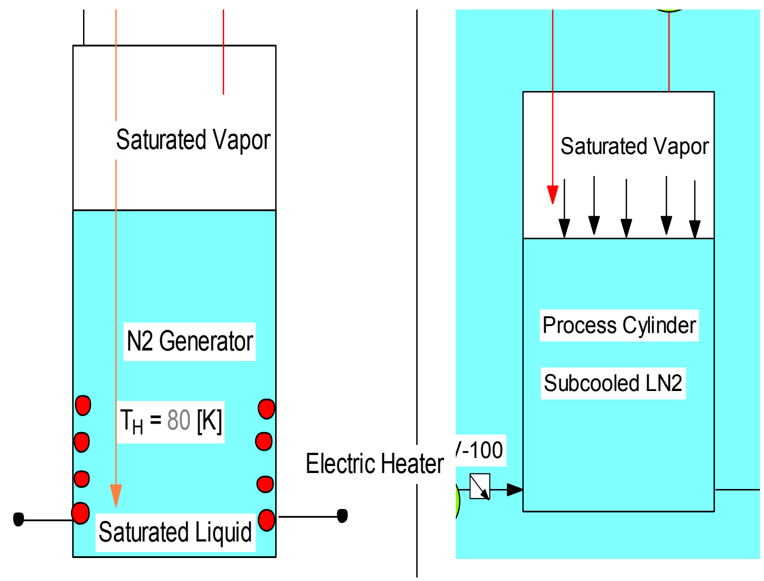
5. OVER-PRESSURE PUMP

What is it?

- **Similar to blowing air into a straw**
- **NOROF LN2 Pumping System**
- **Volume displacement pump**
- **Large expansion ratio 1:130**



- **Major Components**
  - **nitrogen gas (GN2) generator**
  - **Liquid nitrogen (LN2) process cylinder**
  - **Different types of valves**



5. OVER-PRESSURE PUMP

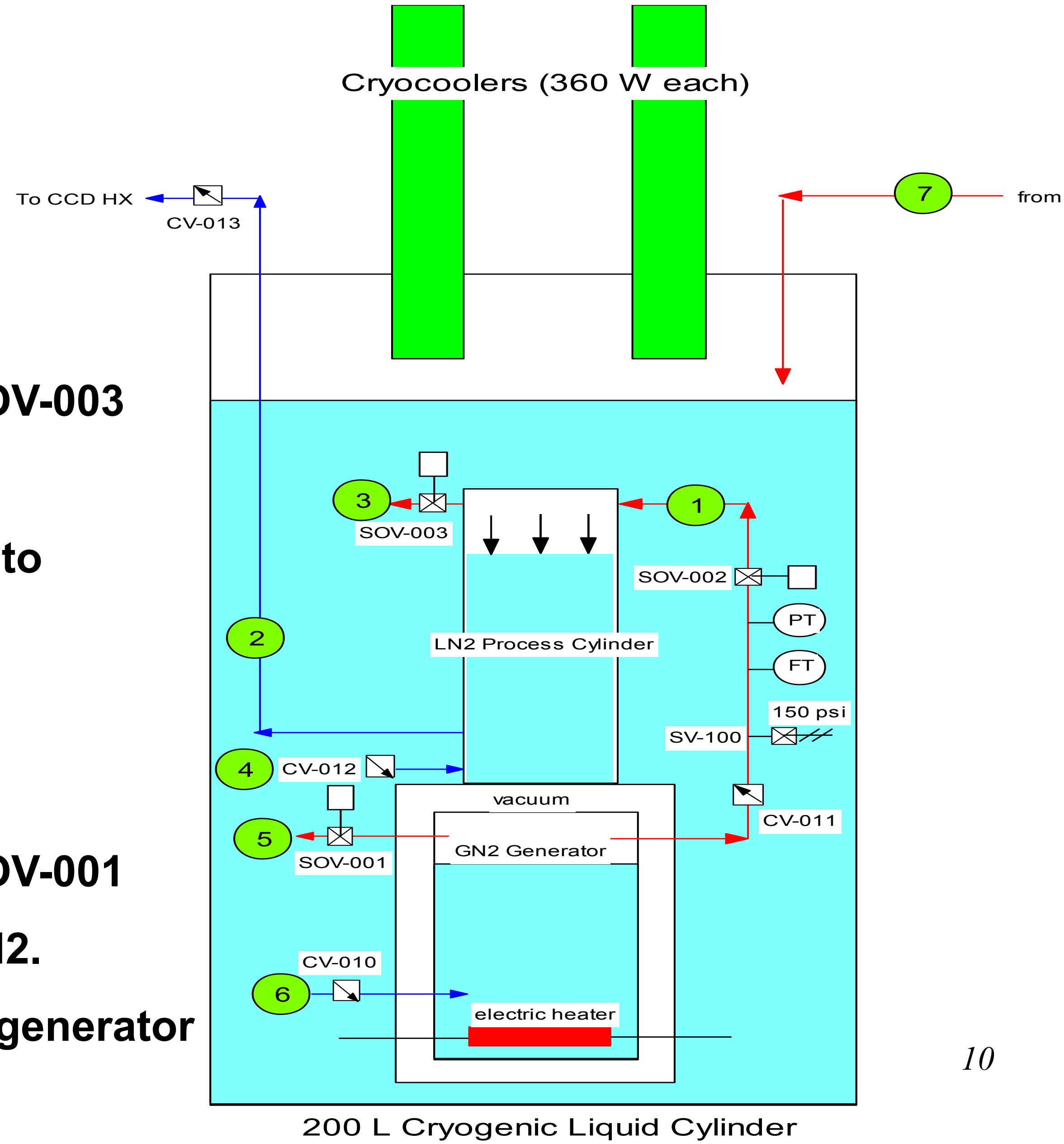
DARK ENERGY SURVEY

1. Schematic

Refilling Operations:

- **LN2 Process Cylinder**
  - **SOV-002 closes and SOV-003 opens- releases GN2**
  - **Subcooled LN2 is sent to process *Line 2***

- **GN2 Generator Refilling**
  - **SOV-002 closes and SOV-001 opens to release the GN2.**
  - **Subcooled LN2 enters generator**



5. OVER-PRESSURE PUMP

DARK ENERGY SURVEY

2. Define Pump Limits

- First Law Efficiency
  - Input versus output

$$\eta_I = \eta_{pump} = \frac{\dot{W}_{pump}}{\dot{Q}_H = \dot{W}_{electrical}}$$

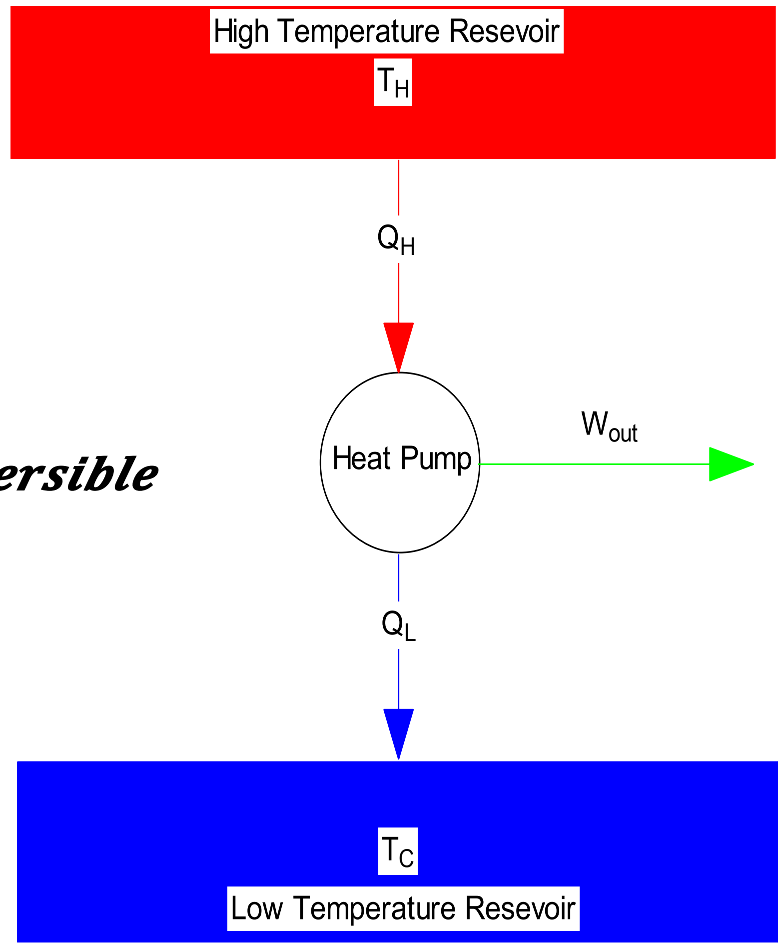
- Max. Thermal Efficiency
  - Maximum output Energy

$$\eta_{I} < \eta_{reversible}$$

$$\eta_{reversible} = 1 - \frac{T_{supply}}{T_{saturation\ of\ N2\ generator}} = 4.55\%$$

- Second Law Efficiency
  - Are we using as much as we could?

$$\eta_{II} = \frac{\eta_I}{\eta_{reversible}}$$



5. OVER-PRESSURE PUMP

DARK ENERGY SURVEY

3. Theoretical Analysis

- Fundamental Equations
  - Thermodynamics
  - Fluid dynamics
  - Heat transfer

$$\dot{W}_{pump} = \frac{\dot{m}_{LN2}}{\rho}(\Delta P_{column} + \Delta P_{friction} + \Delta P_{minor+major})$$

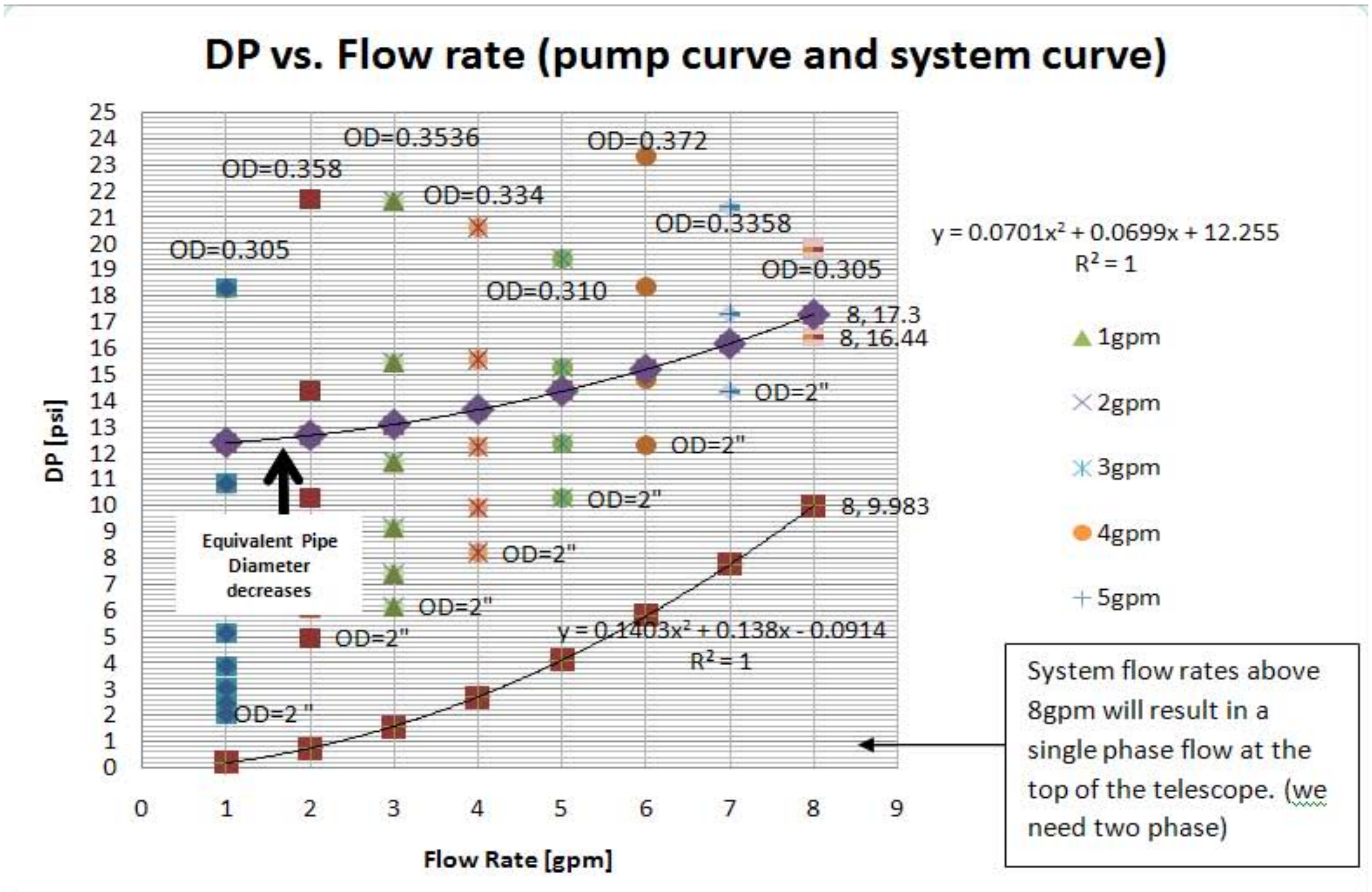
$$\dot{W}_{electrical} = \dot{m}_{N2} h_{fg}$$

- Pump curve and best operational point

- Pump should have:
  - Maximum expansion ratio
  - Maximum efficiency
  - Minimum electrical input

5. OVER-PRESSURE PUMP

DARK ENERGY SURVEY



•Pump curve and best operational points

5. OVER-PRESSURE PUMP

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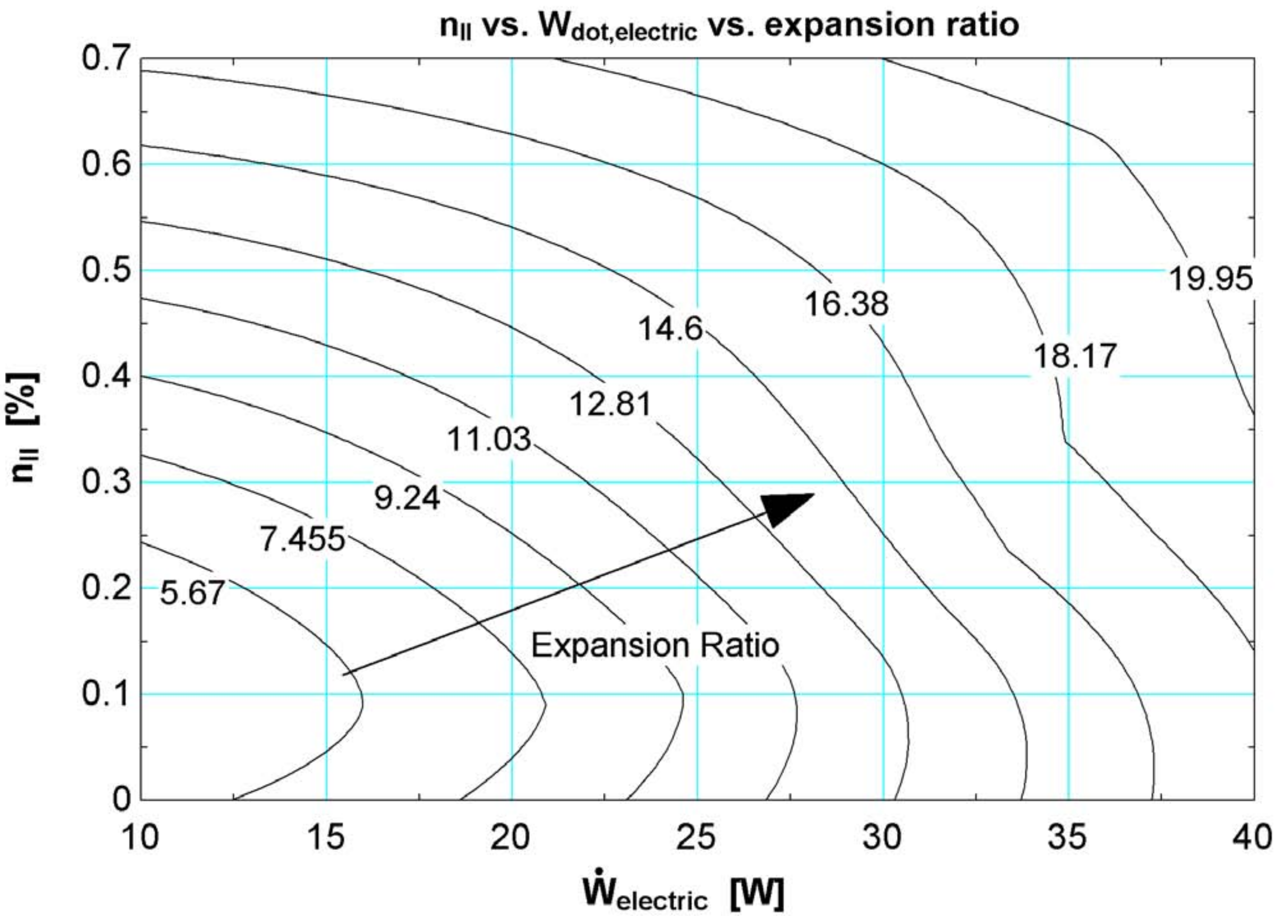

$m_{dot,N2}$=0.000231 kg/s

T_L=100K @ P=8atm

T_H varies

5. OVER-PRESSURE PUMP

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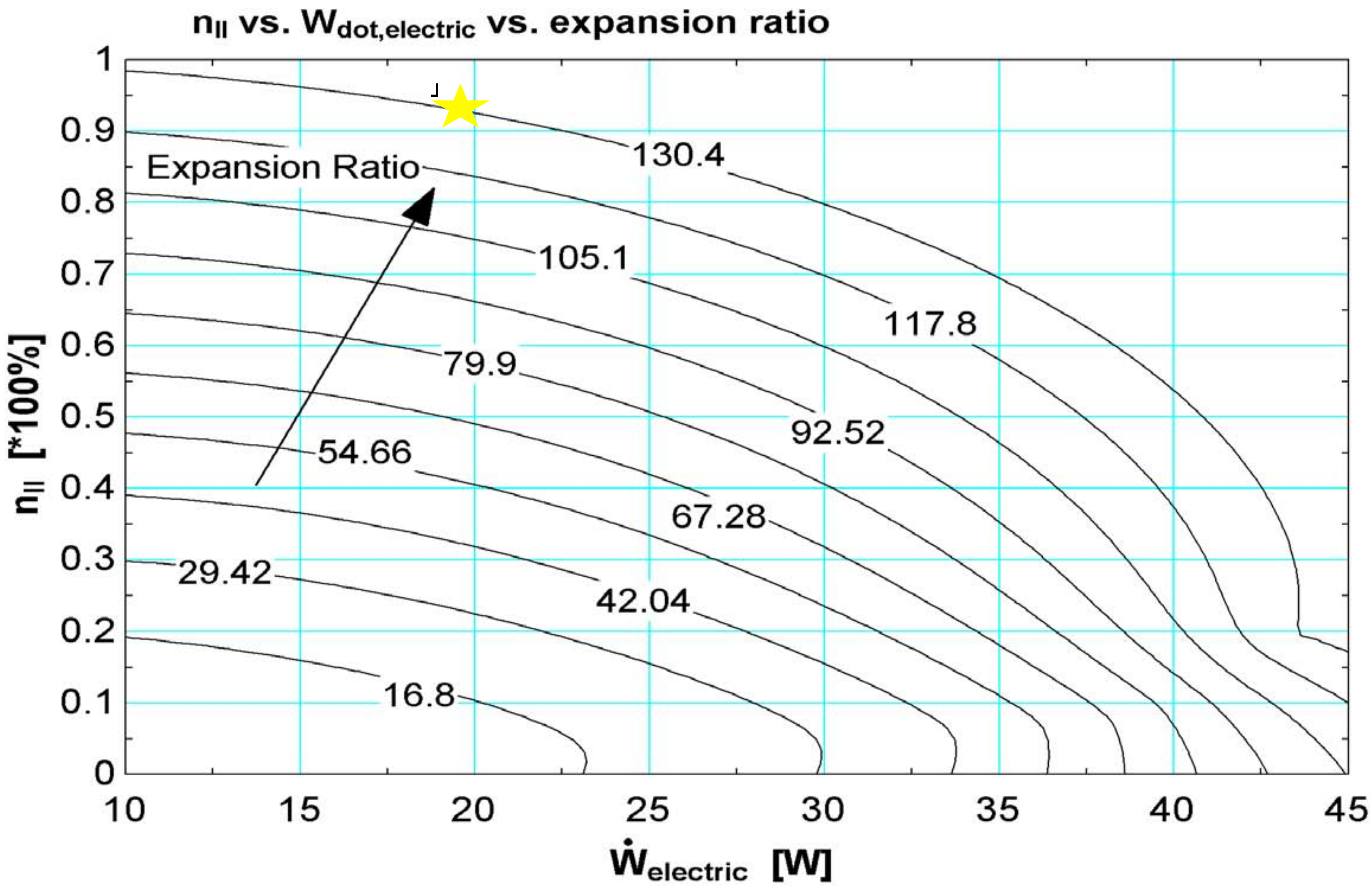


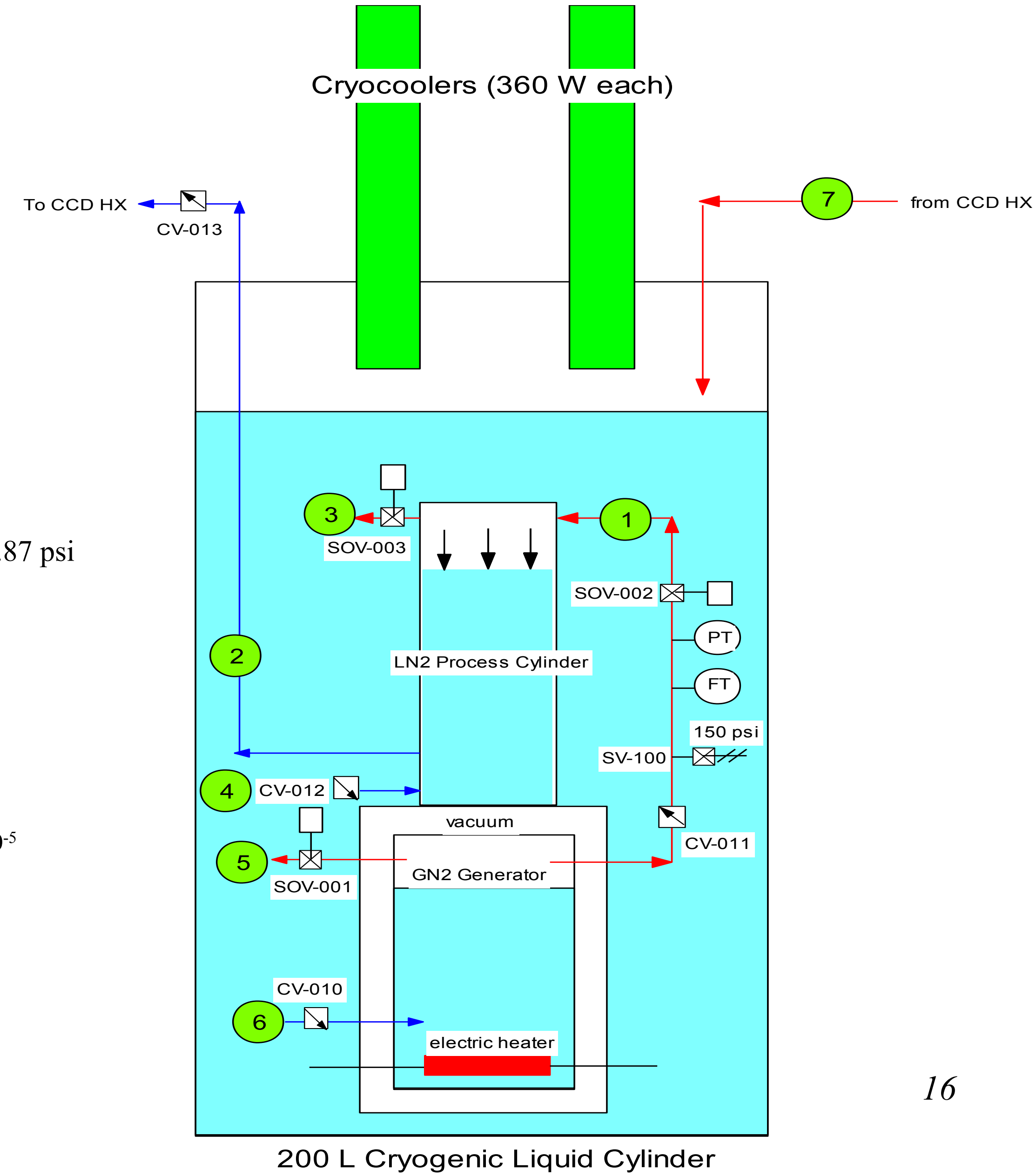
T_L=77K @ P_L=1atm
$m_{dot,N2}$=0.000231 kg/s
T_H varies

5. OVER-PRESSURE PUMP

DARK ENERGY SURVEY

Points From Previous Figure	
Expansion ratio	130.4
W_dot_electric [W]	20
Second Law Efficiency	~95%
First Law Efficiency	~4.50%
Thermal Efficiency (Reversible)	~4.55%
DP_orifice [Pa/psi]	12958/1.87 psi

Calculated Parameters	
T_H [K]	80
P_H [atm]	1.351
rho_N2 [kg/m^3]	6.089
m_dot_LN2 (N2 gas generation) [kg/s]	0.000231
Q_dot_N2 [m^3/s]	3.7937×10^{-5}
Q_dot_N2 [liters/s]	0.0379
Total_Energy_Input [W]	245.5
Total Pressure Drop [psi]	2.249
Q_dot_LN2 (theoretical pump) [gpm]	**0.6**
Required flow rate for current LN2 system [gpm]	**2**



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SURVEY

QUESTIONS?

6. ADVANTAGES AND DISADVANTAGES

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Advantages

- Cheap Parts
  - Solenoid (~$400 for 500000cycles)
- Less moving parts
- Overall Cost of the pump is less (~$9400 estimate)
- Operation in high magnetic fields

Disadvantages

- Poor efficiency (~4.5%)
- Time delay/discontinuous flow at times
- Possible heater burnout

7. PROPOSED RESEARCH METHODOLOGY

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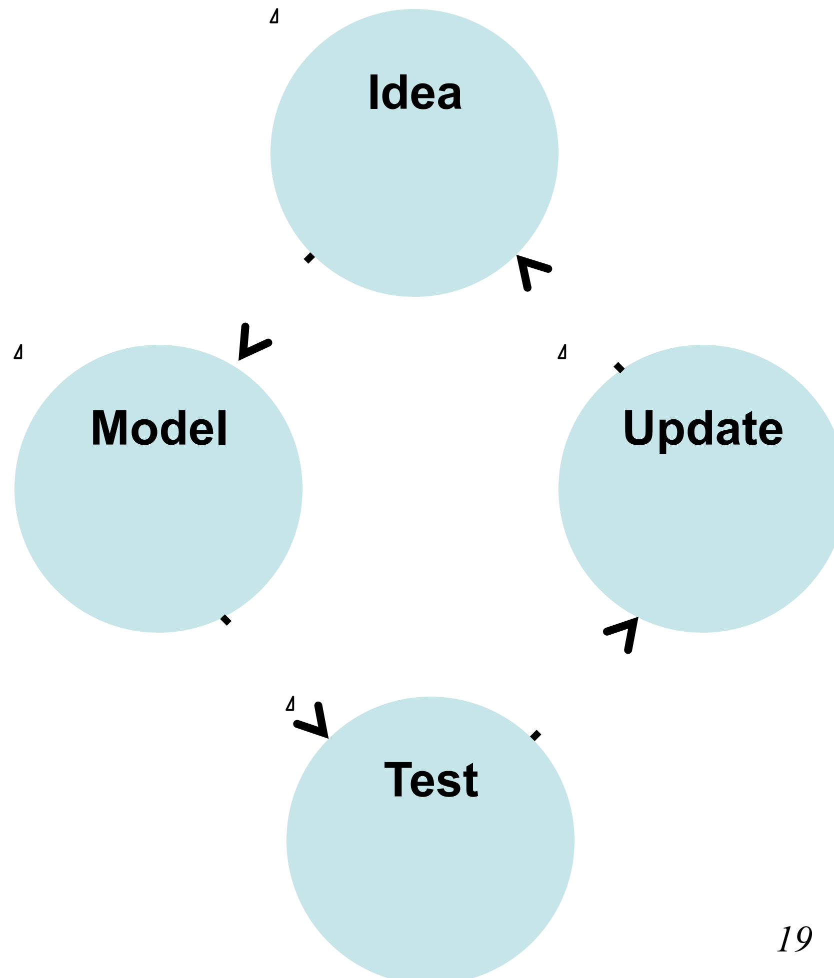
SURVEY

1. Understand the Problem
2. Generate Ideas
3. Analyze ideas using FRSARRC charts
4. Create a math model
5. Concept evaluation and selection
6. Test the design
7. Update the math model
8. Repeat steps 1-7



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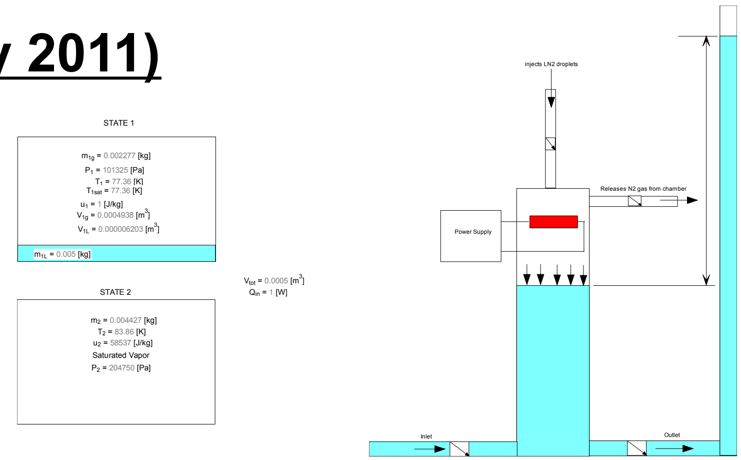
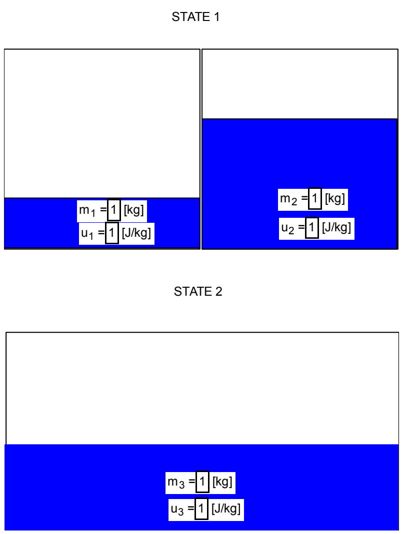
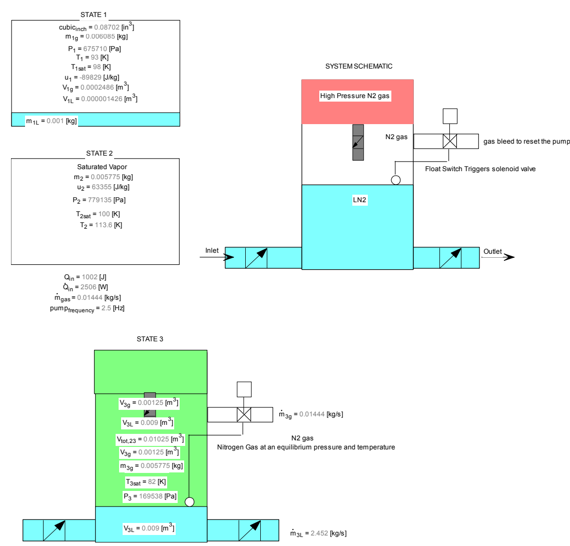
7. PROPOSED RESEARCH METHODOLOGY

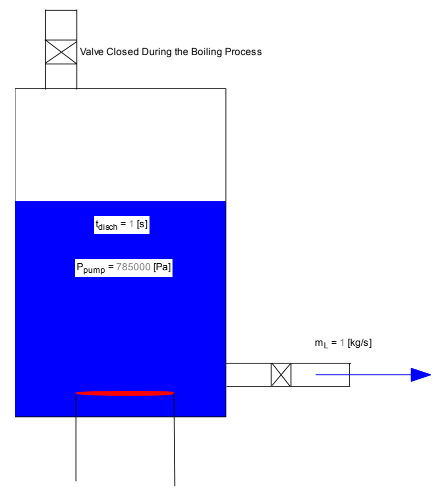
DESIGN PHASE I (May 2011-July 2011)

- Brainstorm
- Research
- Model
- Evaluate solution









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7. PROPOSED RESEARCH METHODOLOGY

<u>DESIGN PHASE II (August 2011-Febraury 2012)</u>

- **Experimentation and update math model**
- **2-3 major experiments are planned for this phase**
  - Test process cylinder in Lab A 200L vessel
    - Currently underway (Next slide)
  - GN2 generator + process cylinder in Lab A
    - Will the cryocooler be sufficient
  - Miscellaneous

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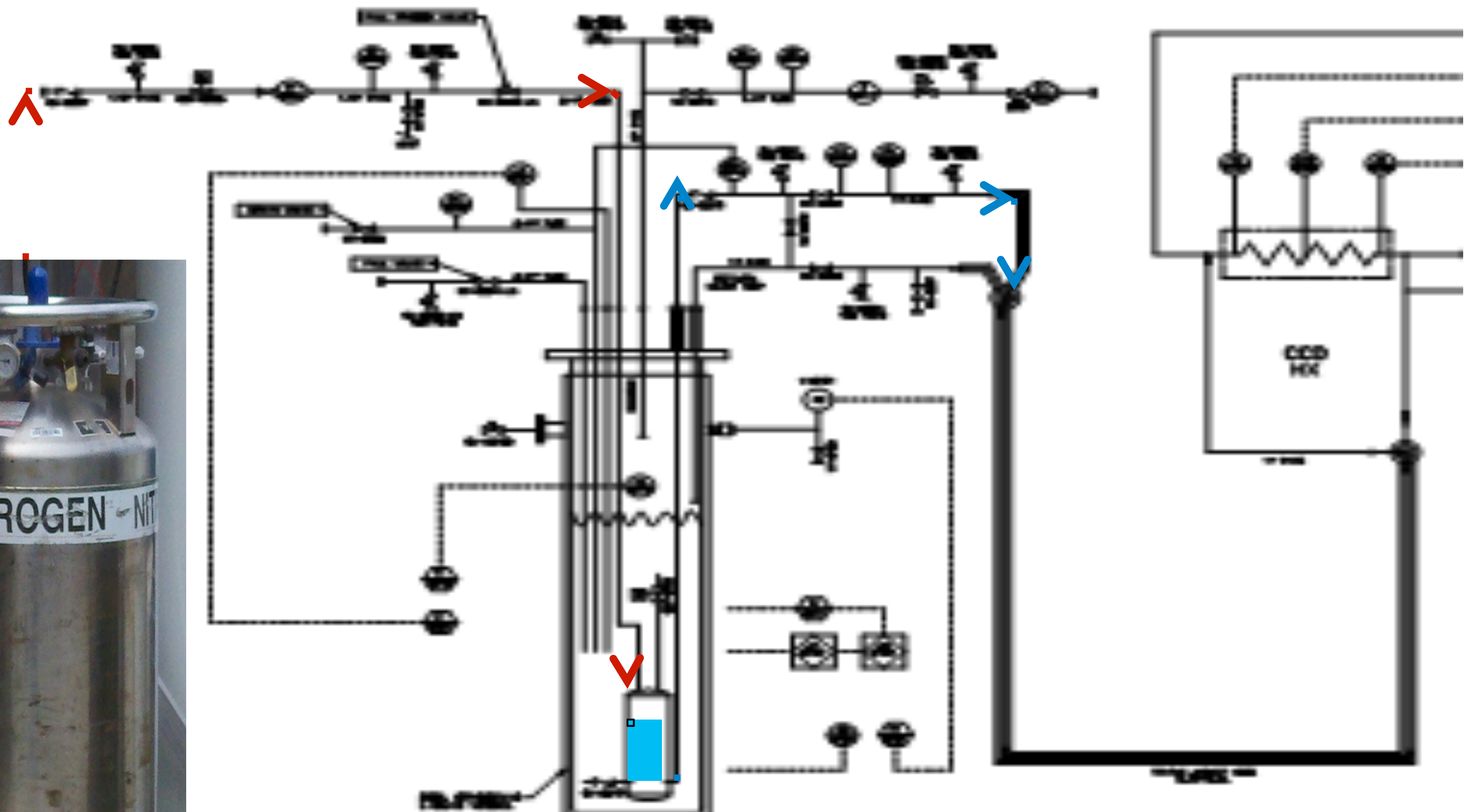
7. PROPOSED RESEARCH METHODOLOGY

DESIGN PHASE II (August 2011-Febraury 2012)



7. PROPOSED RESEARCH METHODOLOGY

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<u>DESIGN PHASE III (March 2012-May 2012)</u>

- Finalize the design
  - Create a P&ID, model, and math model
  - Update documentation package
- Test run on a full scale system in Lab A

QUESTIONS?

8. CONCLUSION

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Good Points

- **Over-pressure pump design**
    - Improved reliability and low maintenance (MTBF~10,000hrs)
    - Low cost (~$9400)
    - Few moving parts

- **Math Models**
    - Prove and update
    - Create an overall system model

- **Future Tests**
    - LN2 process cylinder test
    - GN2 + LN2 process cylinder

8. CONCLUSION

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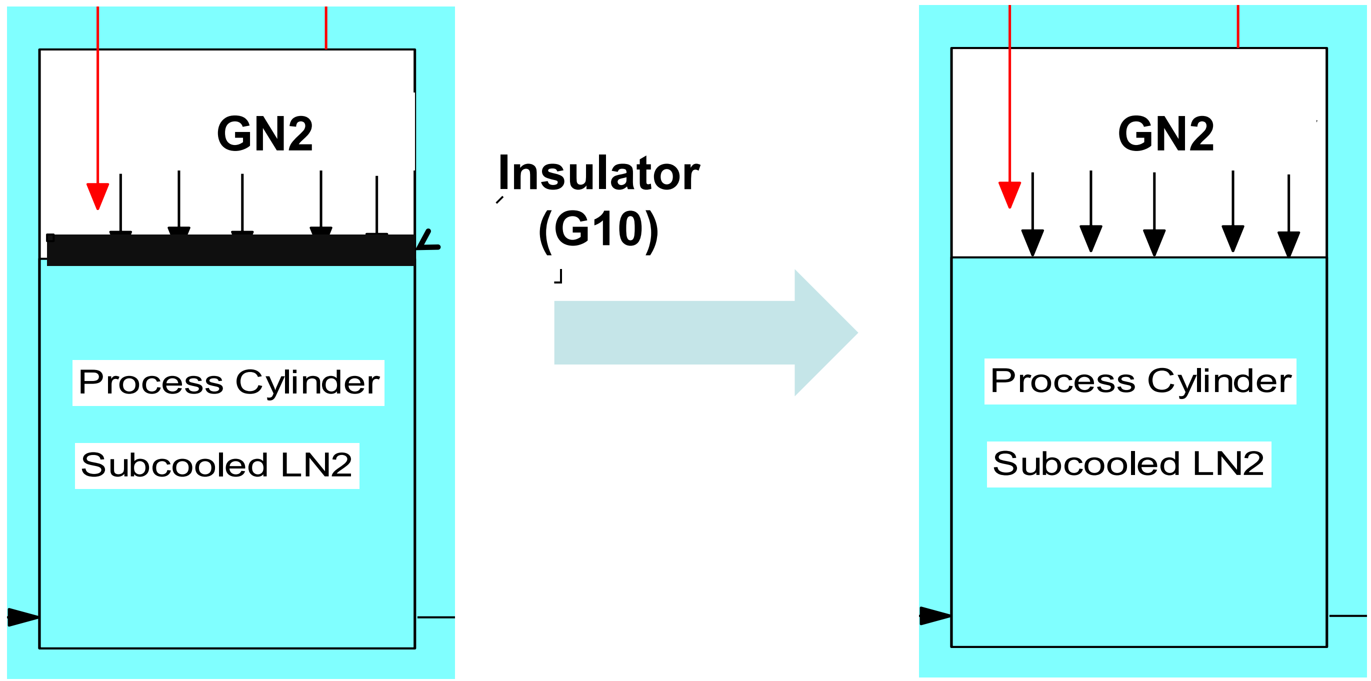
SURVEY

Investigate

- Reliability study
    - Solenoids, check valves, heater, etc.

- Heat Transfer between the LN2 and GN2 in process cylinder



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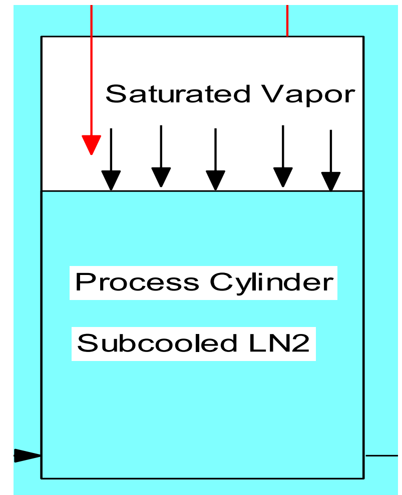
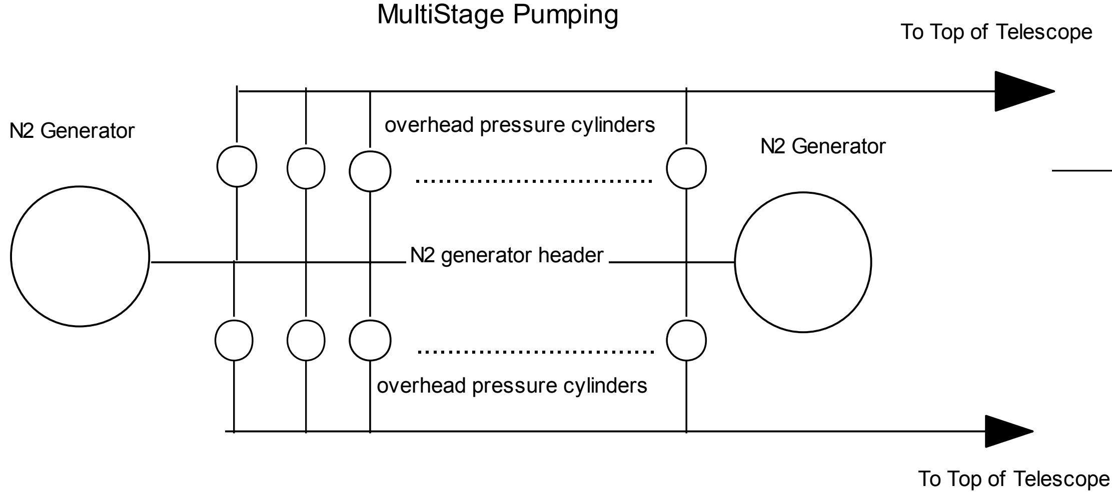
8. CONCLUSION

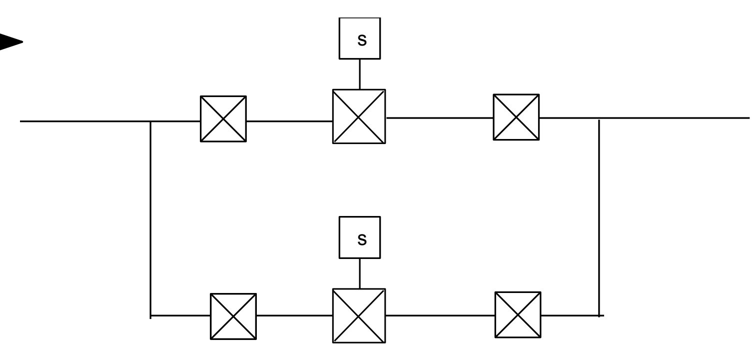


<u>Investigate</u>

- Compressibility Effects of Injected GN2
- Heater (flanged, screw, tape, plate, etc)
- Valves in parallel for increased MTBF
- Multistage pumping
  - Longer MTBF

MultiStage Pumping





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QUESTIONS?

REFERENCES

[1] Cease, H. et al., “Cooling the Dark Energy Camera CCD array using a closed-loop, two-phase liquid nitrogen system” Fermilab-Conf-10-242-PPD 2009

[2] A Cengel, Yunus, and Michael A. Boles. “Thermodynamics: an engineering approach.” 6th ed. 2008. Print.

[3] Roy, Bruce, Donald F. and Theodore Hisao. “Fundamentals of fluid mechanics.” 5th ed. John Wiley & Sons Inc, 2006. Print

[4] Scott, B. Russel. “Cryogenic Engineering.” Prepared for the Atomic Energy Commission.1959.

[5] Lienhard, John H. IV and Lienhard, John H. V. “A Heat Transfer Textbook” 4th ed. Phlogston Press. 2011. E-book.