Energy Efficient Refrigerated Food Processing and Dispensing Machines for Quick Service Restaurants and Food Retail

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Project Summary

Objective and outcome

- Ensure successful transition of quick service restaurant industry from high GWP (>1400) refrigerants to **ultra low GWP** (<10) refrigerant
- At the end of this project, a leak mitigation strategy for propane based soft-serve ice-cream will be developed
- $CO_{2,eq}$ savings potential – 416,000 MT

Team and Partners

Oak Ridge National Laboratory

Taylor Company (CRADA)

Stats

Start date: 10/01/2022

Planned end date: 9/30/2023

DOE budget: $150K, Cost Share: $75k

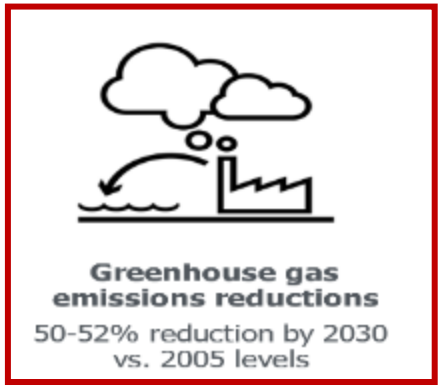
- Milestone 1: Complete experimental evaluation propane leakage in soft-serve machine (FY23 Q2)
- Milestone 2: Complete simulation of refrigerant leakage using computational fluid dynamic modeling of R290 based soft-serve ice-cream machine (FY23 Q3)

Problem

- **High GWP Refrigerant (>1400)**
- **416,000 metric tons of carbon emission**
  - Potential low GWP replacements
    - Natural (GWP < 3)
      - CO_2 (high pressure)
      - Propane (highly flammable)
    - Synthetic
      - R-454C (flammable, GWP:146)
- **No Safety Standards for alternative refrigerants**
- **OEMs need guidance for transitioning**
  - Significance for Taylor Company
    - Global Company with 500 employees
    - Industry leader in the US, 25% share in EU

Alignment and Impact

- 200,000 quick service restaurants in the US
- Current Refrigerant: R449A (GWP= 1400)
- Future Refrigerant: R290 (GWP = 3)
- Higher energy efficiency
- Direct CO_{2e} emission reduction = 99%
- Replacing refrigerant in all soft serve machines would reduce carbon equivalent by 416,000 metric tons
- Increases global footprint of US OEM



Approach

- **Previous Years work identified significant challenges in migrating towards low GWP solution**
  - Modeling Prototype Low GWP based Soft-Serve Ice-cream machine
    - Thermodynamic Analysis of CO_2 based machine
    - Evaporator and Condenser Modeling
  - Laboratory Evaluation
    - R454C based soft serve machine at different ambient temperatures showed insufficient capacity

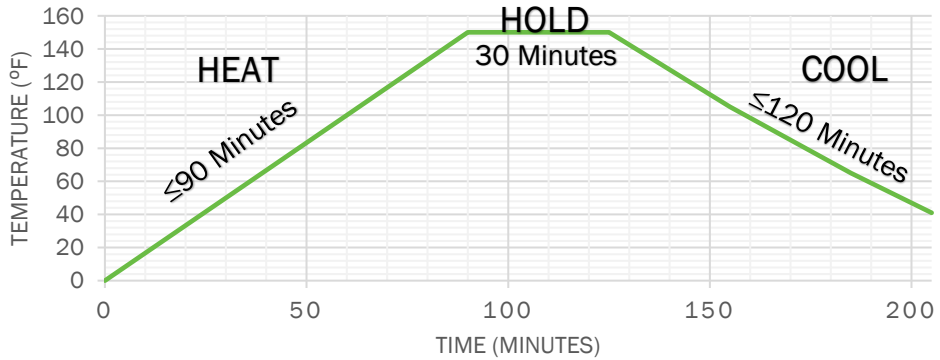
Approach

- **CO_2 system analysis**
  - Thermodynamic Model development
  - Heat Pump Design Model
- **Issues**
  - High Operating Pressure
  - Inefficient
- **Flammable refrigerants**
  - R454C (Mildly Flammable): GWP-146
  - R290 (Highly Flammable): GWP-3

	System	Coefficient of Performance	Discharge Temperature (˚F)	Condenser Pressure (psia)	Refrigerant Charge (lb/hr)	System Complexity	Store Retrofit
Single Stage System	CO_2 Direct Expansion (DX) System	1.18	284	1350	196	Simple	NO
	CO_2 DX system with SLHX	1.25	326	1310	170	Simple	NO
	CO_2 DX with Gas Bypass	1.21	273	1345	198	Simple	NO
Two Stage System	CO_2 DX system with SLHX (2 stage expansion)	1.24	283	1331	189	Moderate	NO
	CO_2 DX system with 2 stage compression (intercooler)	1.49	188	1335	167	Moderate	NO
	CO_2 system with 2 stage compression and 2 stage expansion	1.4	186	1335	189	Moderate	NO
	CO_2 Booster System	1.42	232	1229	214	Moderate	NO

Approach

- **R454C Machine Evaluation**
  - Continuous Run Test
    - Product Quality
    - Product Draw Rate
  - Capacity and Hopper Cooling Test
    - Refrigeration Capacity
    - Recovery time
  - Heat Treatment Test
    - NSF/ANSI 6- Dispensing Freezers
    - Product temperature > 150°F for 30minutes

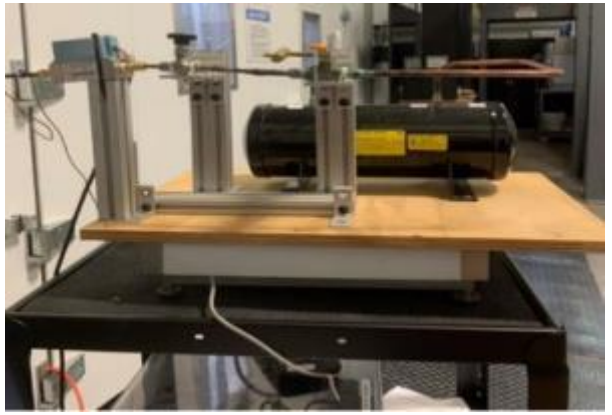


Approach

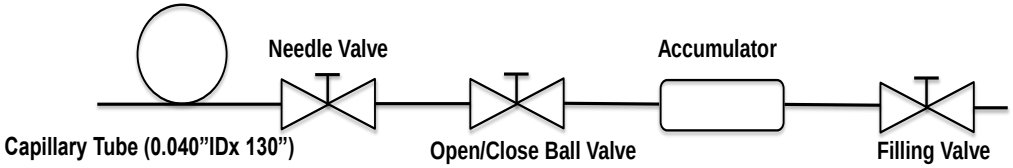
- R290 is only remaining ultra low GWP option
- Flammable
- Taylor C602 machine has over 65 components not rated for hazardous environment
- No Safety Standards for flammable refrigerant usage in soft serve machines
- Compartmentalize system charge to minimize potential leak under 150 gms

Infrared sensor

Instrumented Prototype machine



Propane Leak Setup



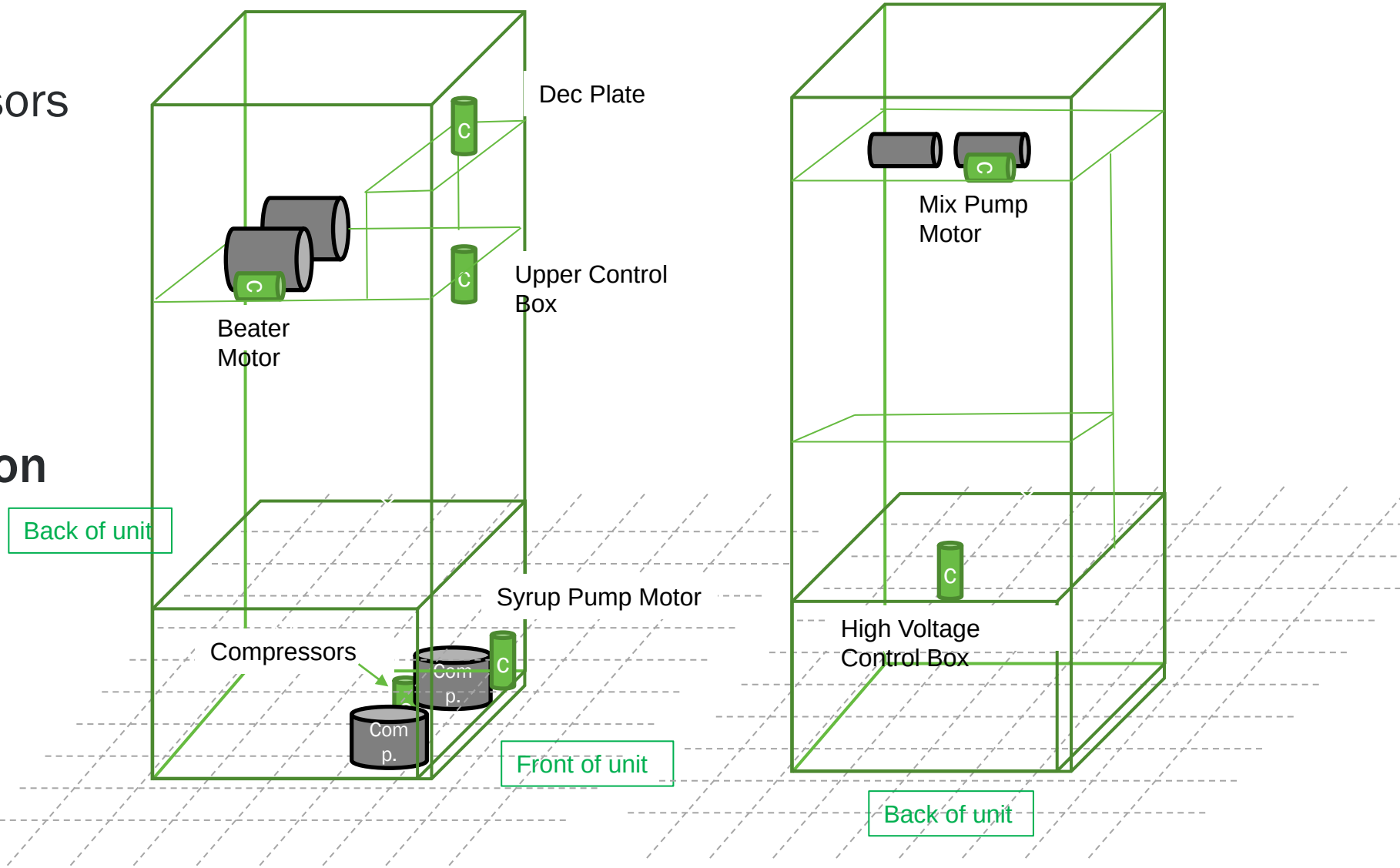
Propane Leak Setup Schematic

Progress

- Adopted IEC 60335-2-89
  - » Safety standard for commercial refrigeration appliances and ice-makers
  - Unprotected Cooling System: 22.112 – Not Energized
    - Through an orifice for 1 hour
    - 80% of nominal charge within 10 mins
    - Maximum conc. should not exceed 75% LEL
    - Maximum conc. should not exceed 50% LEL for more than 5 mins
  - Outside the Food Storage Compartment: 22.113 –Not energized
    - Constant rate through an orifice for 1 hour
    - 50% of nominal charge within 1 hour
    - Maximum conc should not exceed 75% LEL
    - Maximum conc. should not exceed 50% LEL for more than 5 mins

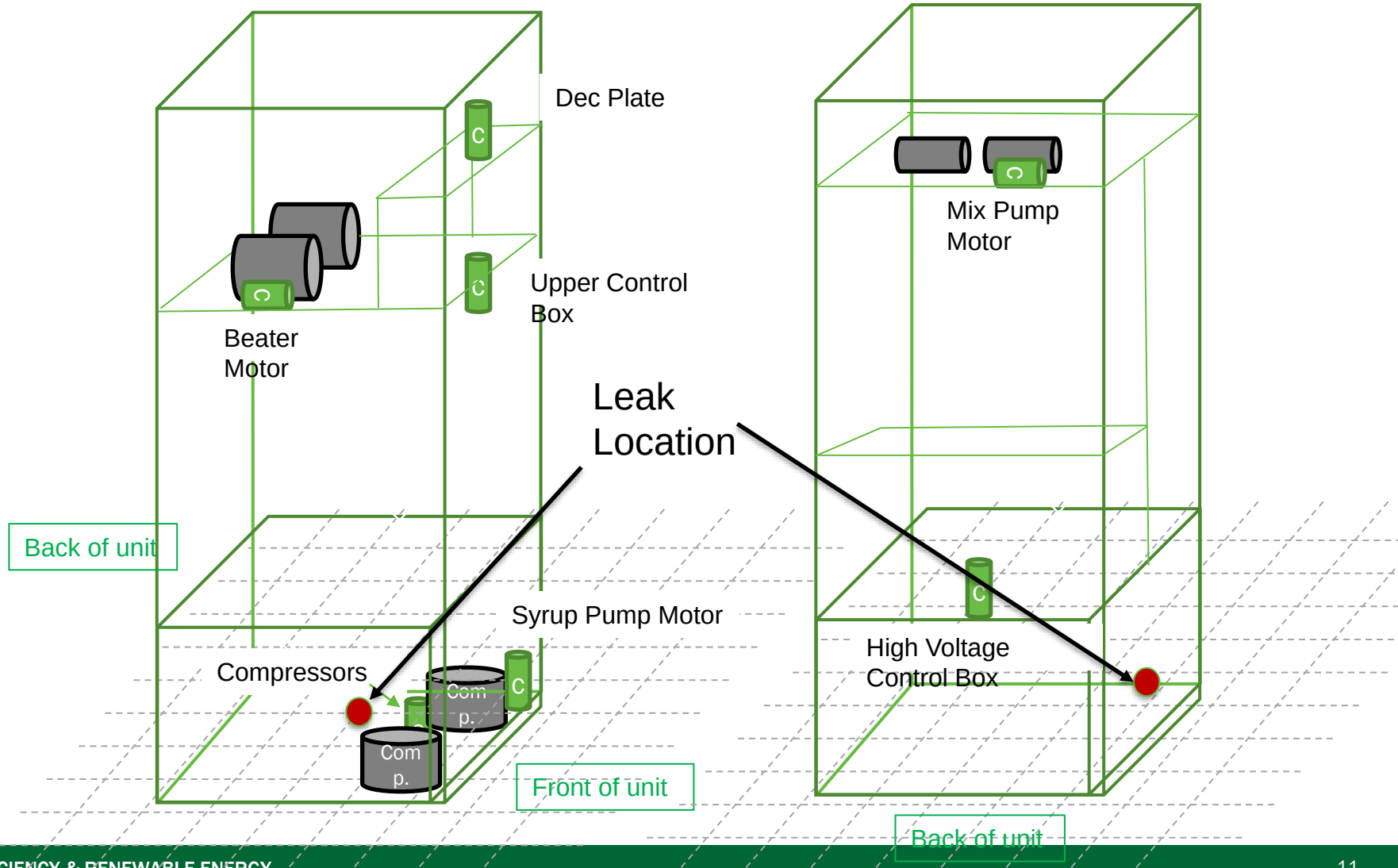
Progress

- **Sensors**
  - 11 IR propane sensors
  - 7 inside, 4 outside
- **Leakage Study**
  - 150g leak
  - 300g leak
- **No Leakage Mitigation**



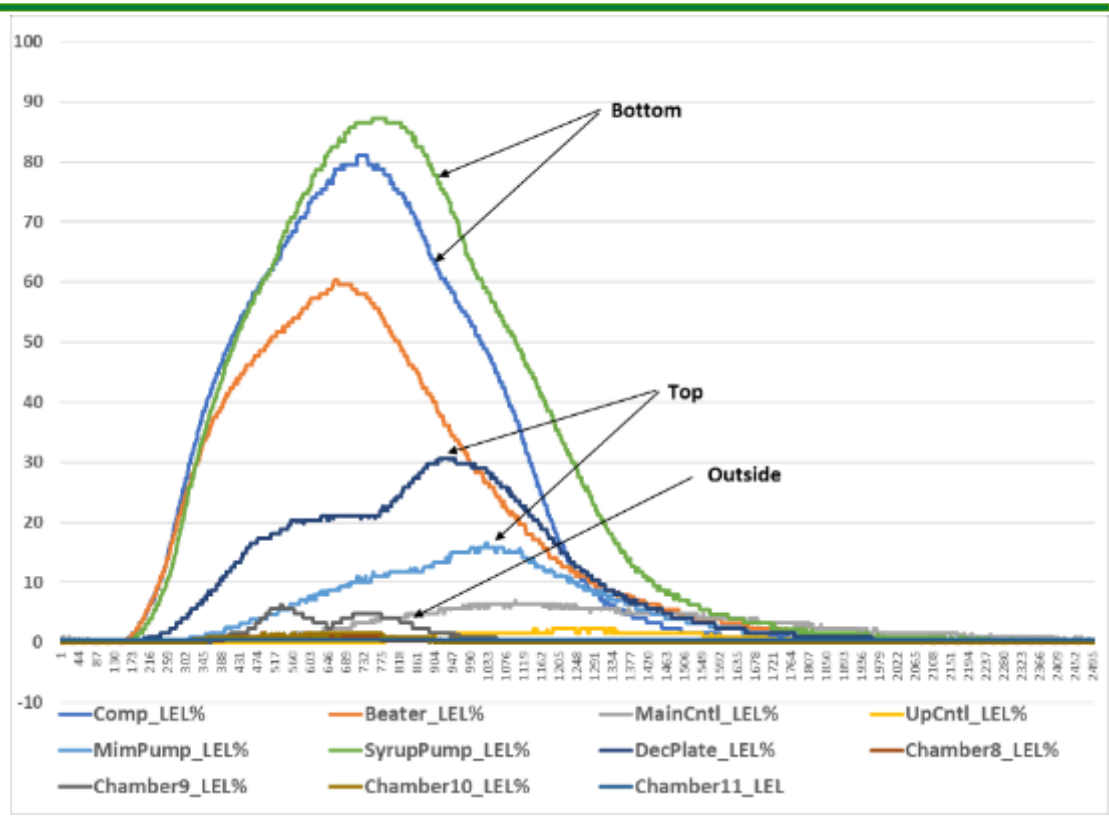
Progress

- Bottom Leak using 300gms (Standard 60335.2.89: 22.113)



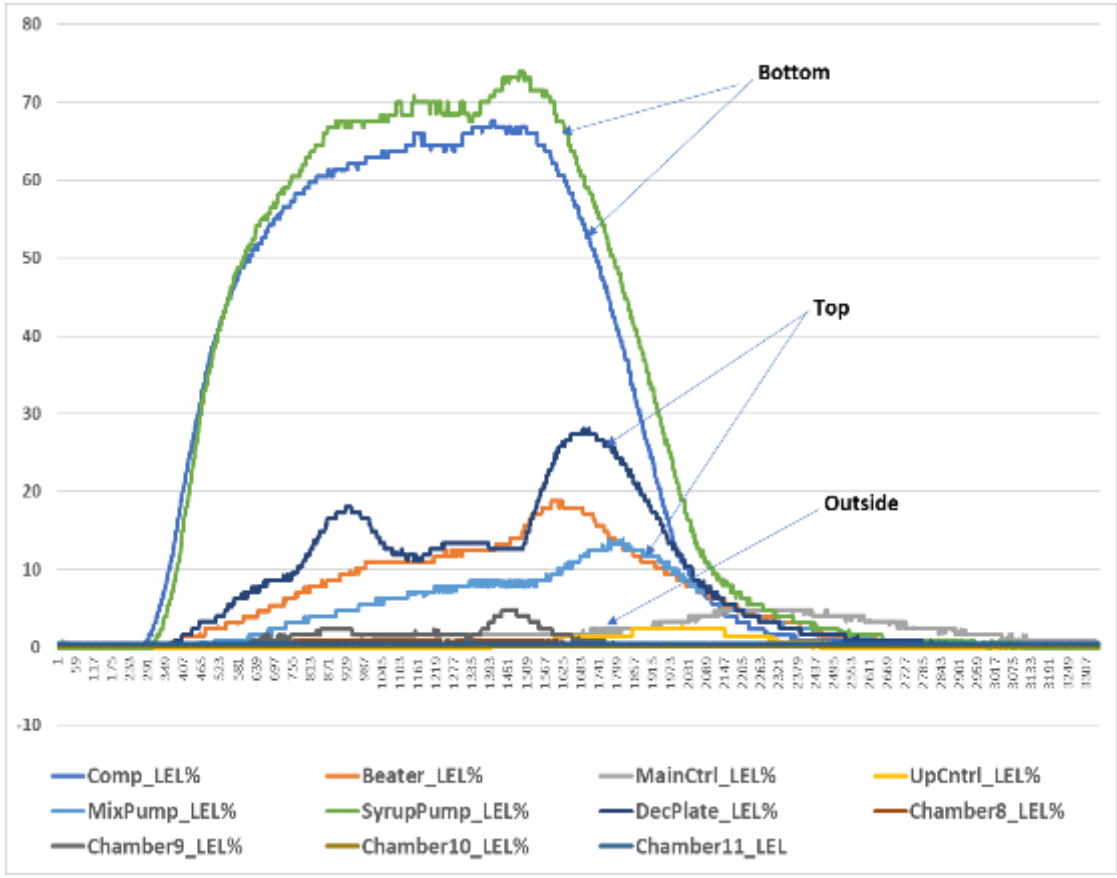
Progress

- **Bottom Leak using 300gms (22.113)**
  - Representing Compressor Leak
  - Propane concentration levels inside machine
    - 50% LEL within 2 mins of leak initiation
    - **Test Failed**: 75% LEL within 4 mins of leak initiation
    - Gas conc continued to increase in top after shutdown
    - Peak conc reached 88%
  - Minimal leakage to surrounding
    - Peak concentration never exceed beyond 6% LEL



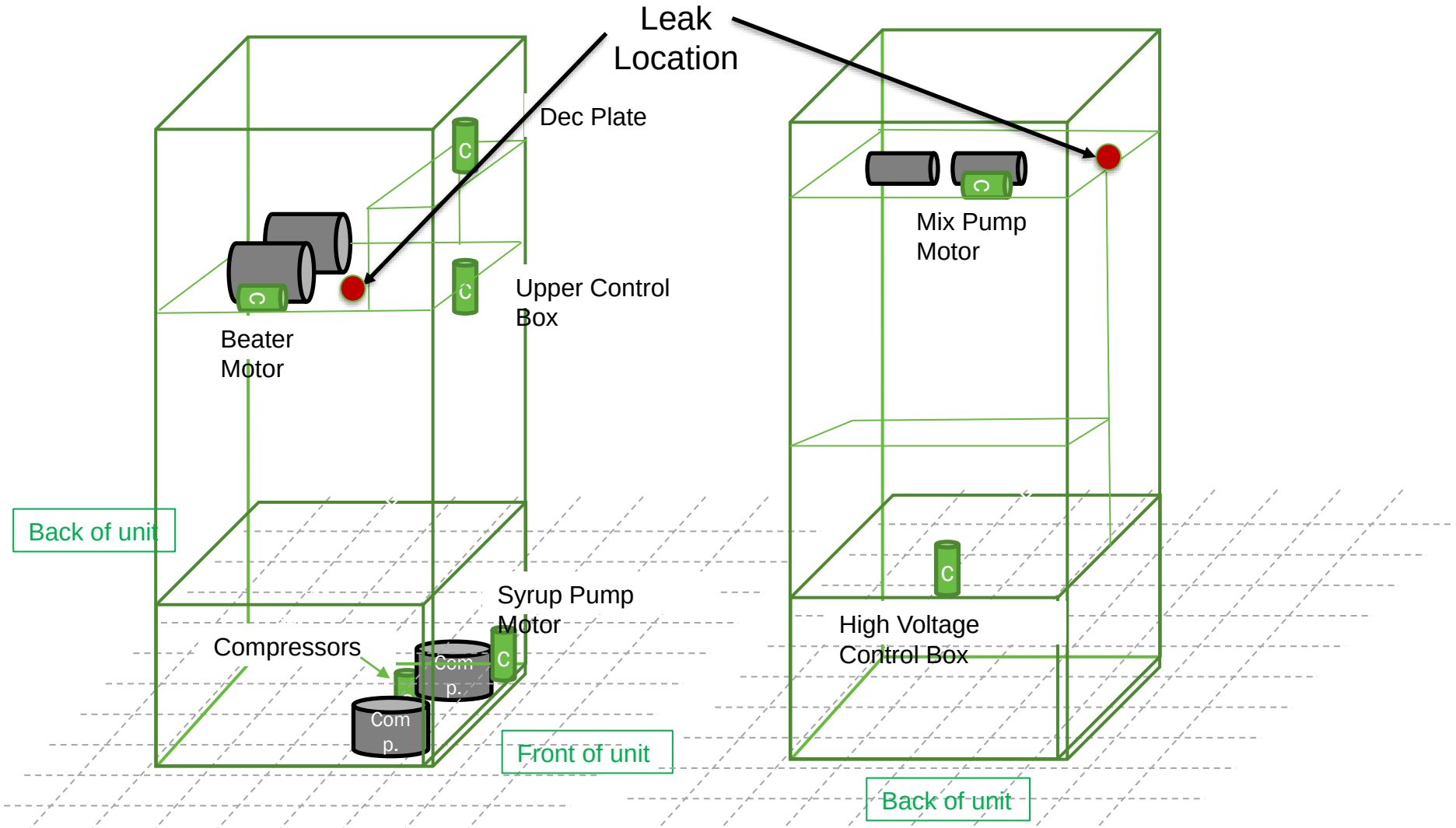
Progress

- **Bottom Leak using 150gms (22.113)**
  - Representing Compressor Leak
  - Propane concentration levels inside machine
    - 50% LEL within 4 mins of leak initiation
    - **Test Failed**: Conc. level exceed 50% for more than 5 mins
    - Peak conc reached never exceed 74 LEL%
  - Minimal leakage to surrounding
    - Peak concentration never exceed beyond 5 LEL% LEL using 150 gms (22.113)



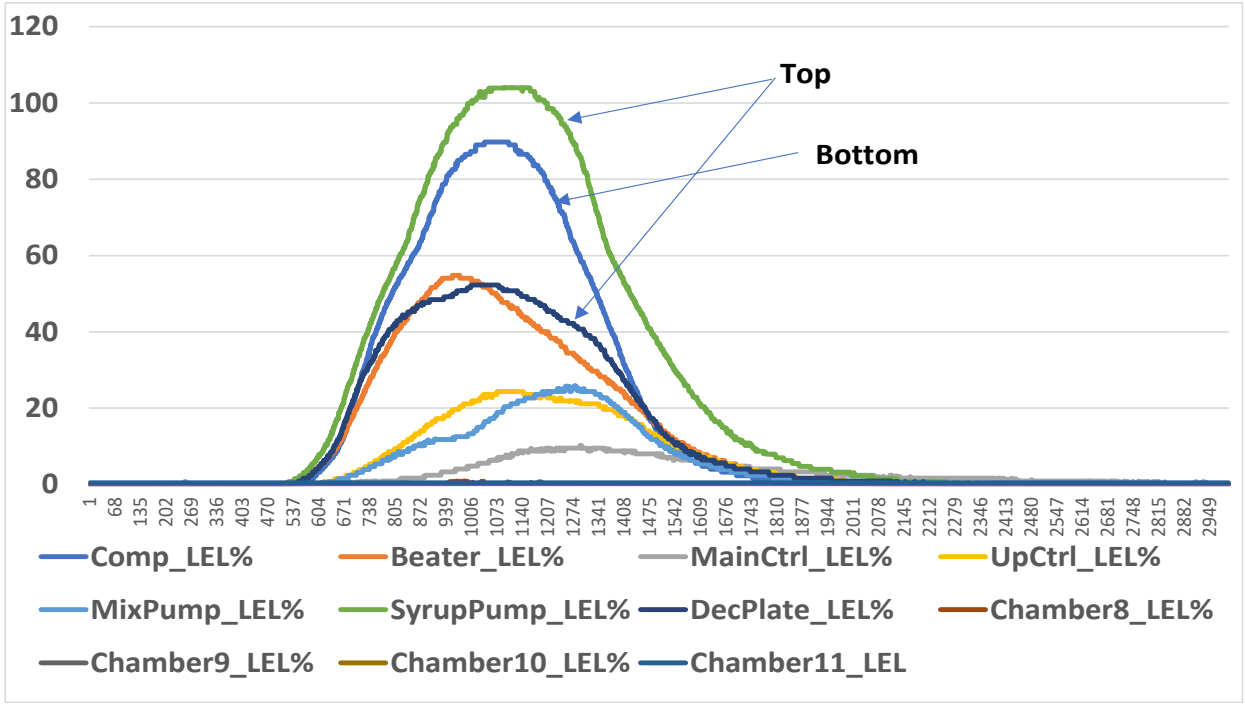
Progress

- Top Leak using 300gms (Standard 60335.2.89: 22.113)



Progress

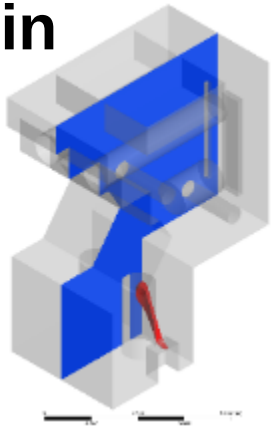
- **Top Leak using 300 gms (22.113)**
  - Representing Evaporator Leak
  - Propane concentration levels
    - 50% LEL within 2 mins of leak initiation
    - 75% LEL within 3 mins of leak initiation
    - Peak conc reached above LEL
  - Minimal leakage to surrounding
    - Peak concentration never exceed beyond 3% LEL using 300 gms



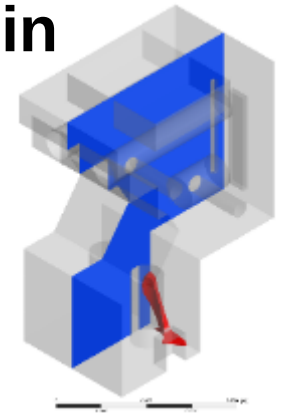
Leak Diffusion

- Leak diffusion in a static environment
- Leak source and the CAD model
- Concentration profiles
- Flammable zone is shown in red color (3D)
- Model agrees with experimental results
- Leak rate – 1.05 g/min

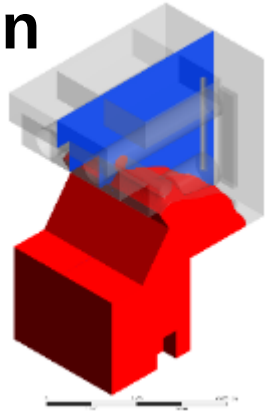
1 min

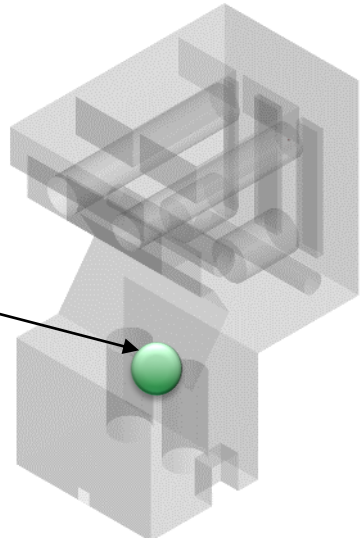


3 min



10 min

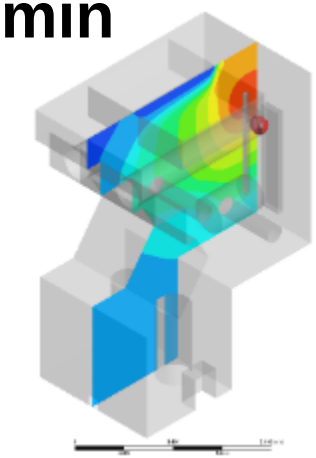




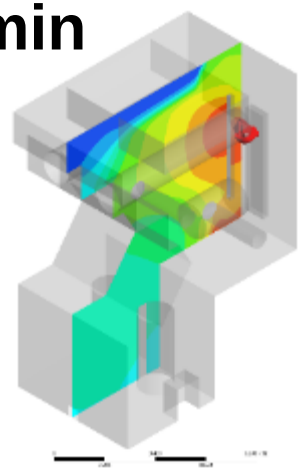
Leak Diffusion (contd.)

- Leak diffusion in a static environment
- Leak source and the CAD model
- Concentration profiles
- Flammable zone is shown in red color (3D)
- Model agrees with experimental results
- Leak rate – 1.05 g/min

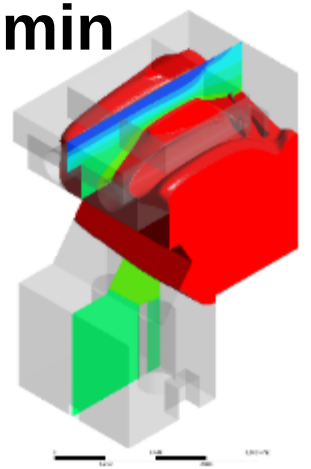
1 min



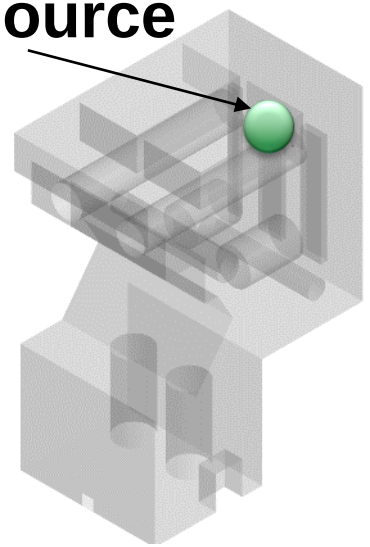
3 min



10 min



Leak source



Lessons Learned

- Evaporator leak mitigation is critical
- Trends of propane concentration in energized machine are expected to match unenergized machine trends
- Shut-off valves and charge compartmentalization is needed to reduce propane conc levels
- Redesigning of condenser location needed

Future Work

- **Propose leak mitigation methods**
  - Identify strategic placement of sensor(s) within the systems
  - System controls integrated mitigation
- **Condenser Fan Design Modification**
  - Vertical Coil vs. A-Coil Design

Thank you

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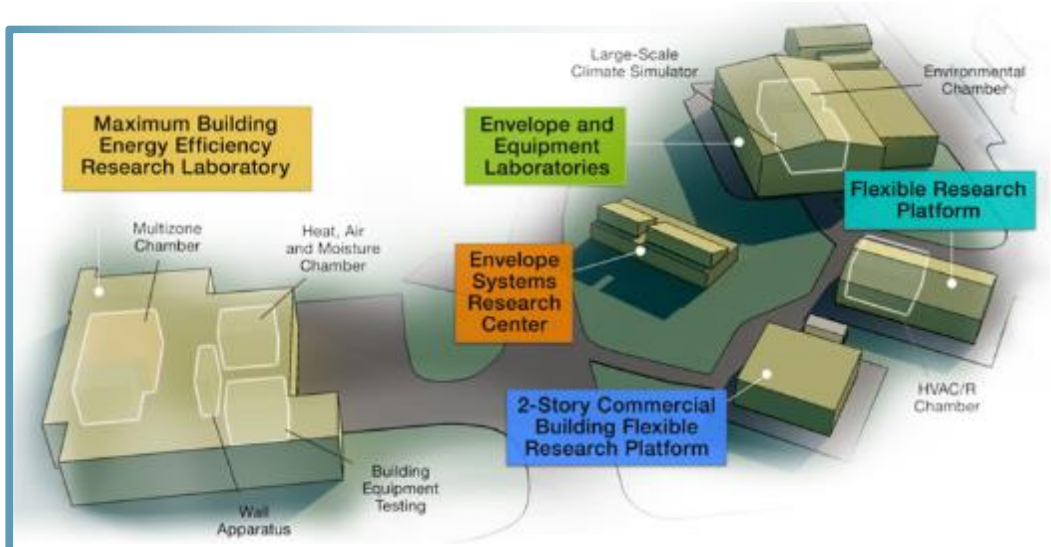

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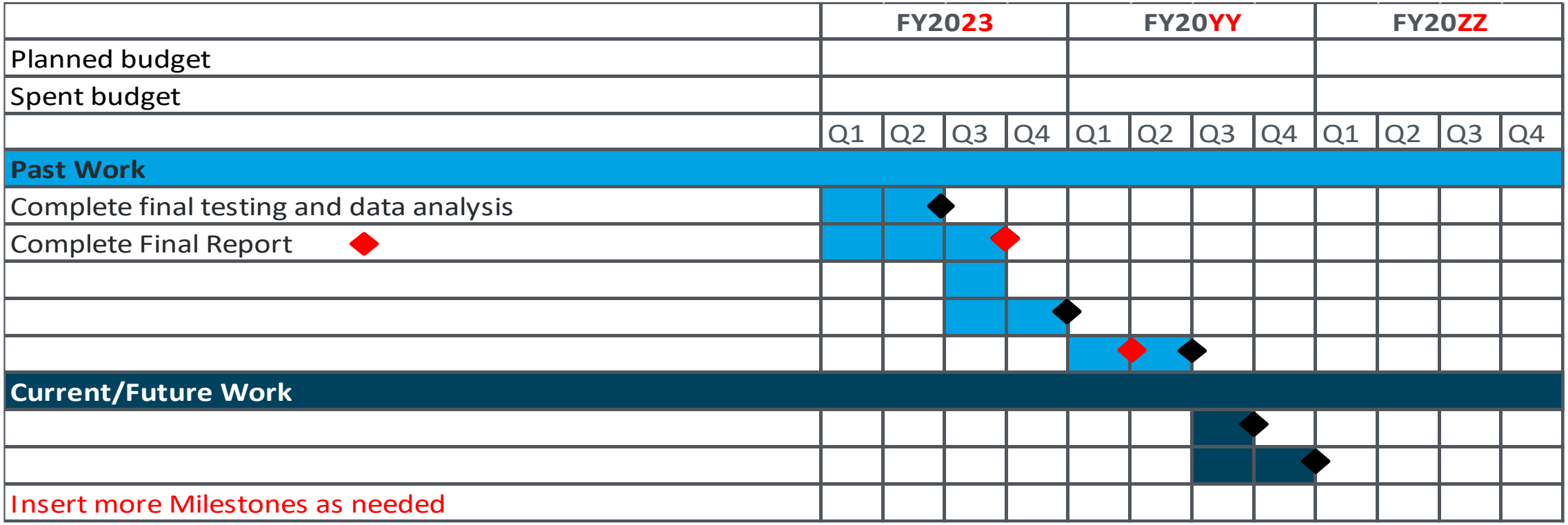
REFERENCE SLIDES

Project Execution

Required to complete, but does not count towards total slide count and doesn't need to be focused on during presentation



- Go/no-go decision points
- Explanation for slipped milestones and slips in schedule

Team

- **Oak Ridge National Laboratory**
  - **Research Team**
    - Vishaldeep Sharma
    - Bo Shen
    - Praveen Cheekatamarla
    - Tugba Turnaoglu
    - Mingkan Zhan
  - **Service & Safety Team**
    - Tony Gehl, Tim Dyer, Jeff Taylor and Gerald Barth
- **Taylor Company**
  - Stephen Wadle (Senior Project Engineer)
  - Jim Minard (COO)