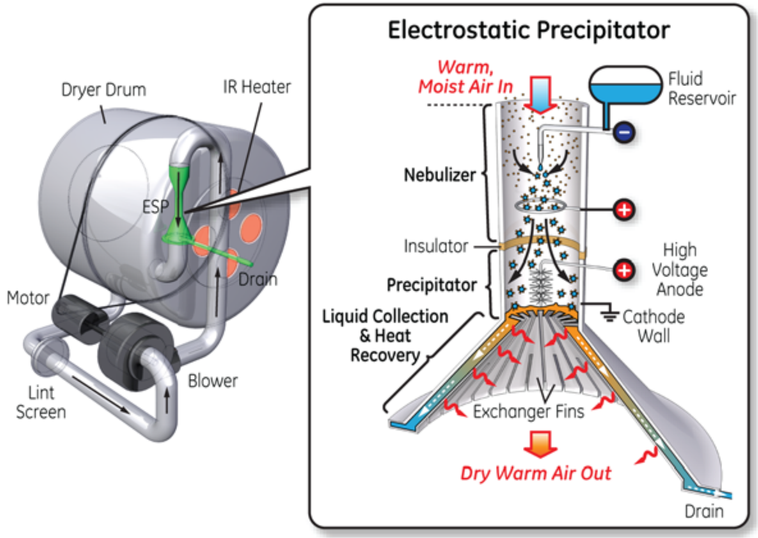
Energy Efficient Clothes Dryer with IR Heating and Electrostatic Precipitation

2017 Building Technologies Office Peer Review

Project team members left to right Tom Stecher, Stan Weaver, Ralf Lenigk, Martin Vysohlid, Arin Cross, Francisco Moraga, absent from photo Nannan Chen.

Program Objective: *Demonstrate a Ventless Residential Dryer with a EF >4.04*



Technical Approach

- Ventless closed loop system
- Advanced IR heating
- Modulated heater drying cycle
- Electrostatic Precipitator (ESP) for humidity removal

Technical Challenges

- Lint fouling in exchanger
- Efficient heat spreading in drum
- IR heater/ESP optimization
- ESP efficiency near end of cycle

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GE Global Research

Project Summary

Timeline:

Start date: 10/1/2014

Phase 1 to 2 delay 6/16-9/16

Planned end date: 9/30/2017

Key Milestones

Milestone 1: Demonstration of an ESP exchanger Meeting program goals; 6/30/2016, Complete

Milestone 2: Demonstrate Integrated prototype MVP dryer operating at an EF goal of >4.04; 9/30/2017

Key Partners:

None

Budget:

Total Project $ to Date:

DOE: $ 585,915

Cost Share: $146,479

Total Project $:

DOE: $1,040,040

Cost Share: $260,001

Project Outcome:

The goal of the program is to design, build, and demonstrate a residential ventless dryer with an energy factor (EF) of >4.04.

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Purpose and Objectives

Problem Statement: Current residential dryer EF's (lbs/kWh) are ~3.73. DOE MYPP target is an EF of 6.0 by 2020 at a payback of less than 5 years.

- **Target Market and Audience**: Target market is the US residential clothes dryer market, consisting of ~ 84 million dryers, consuming ~64 billion kWh per year.

Impact of Project: A residential ventless dryer with an EF of 4.8 translating to energy savings 50.8 billion kWh (appliance and make up air savings). The planned EF is concurrent with DOE 2020 goals of 6.0.

a. Near-term outcomes (during or up to 1yr after project)? – Licensing of the proposed technology.
b. Intermediate outcomes (1-3yr after project)? – Commercialization of the proposed dryer and realization of energy savings.
c. Long-term outcomes(3yr.+ after project)? Technology insertion broadening into other applications; i.e. industrial drying and smoke stack and exhaust effluent remediation.

Approach

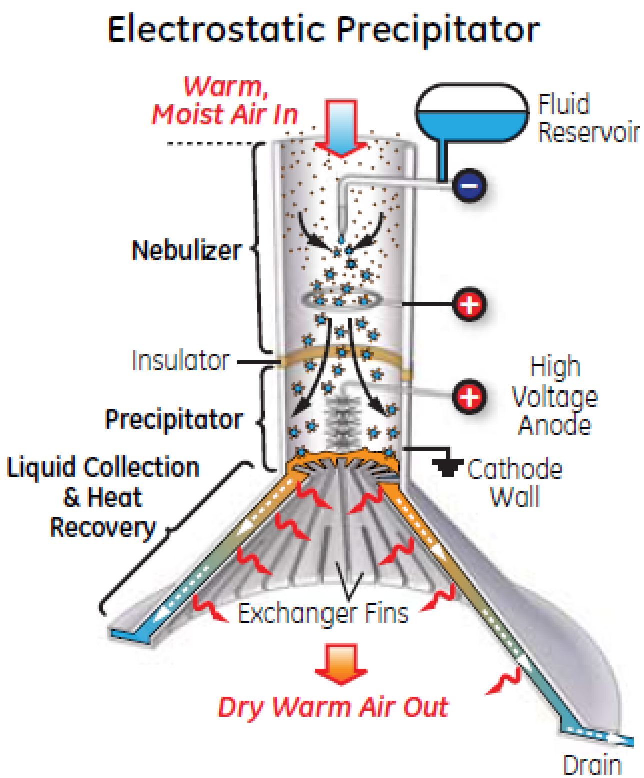
Approach: Development of next generation technology prototypes.

- Construction of a "variable" dryer output simulator
- Model, design, testing, optimization and demonstration of key technologies
  - ESP/Exchanger and IR heaters
- Integration of key technologies into working prototypes meeting program goals

Key Issues: Current ESP/Exchanger efficiency of 50% will require higher steam extraction rate, when compared to a conventional dryer, or multiple stages to meet current drying times.

Distinctive Characteristics: High EF, non vented dryer with <5yr payback.

- Combined Nebulizer/ESP for water extraction and recycling of latent heat
- IR heating system tuned (~3um) for optimum heat transfer to water



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Progress and Accomplishments

Accomplishments: Demonstration of an ESP/Precipitator with ~50% extraction efficiency. Phase 1 Go/No-Go milestone met. Phase 2 in progress.

Market Impact: Applications of the technology are broad and far reaching from drying, dehumidification, and industrial effluent cleaning. Current business status requires licensing strategies.

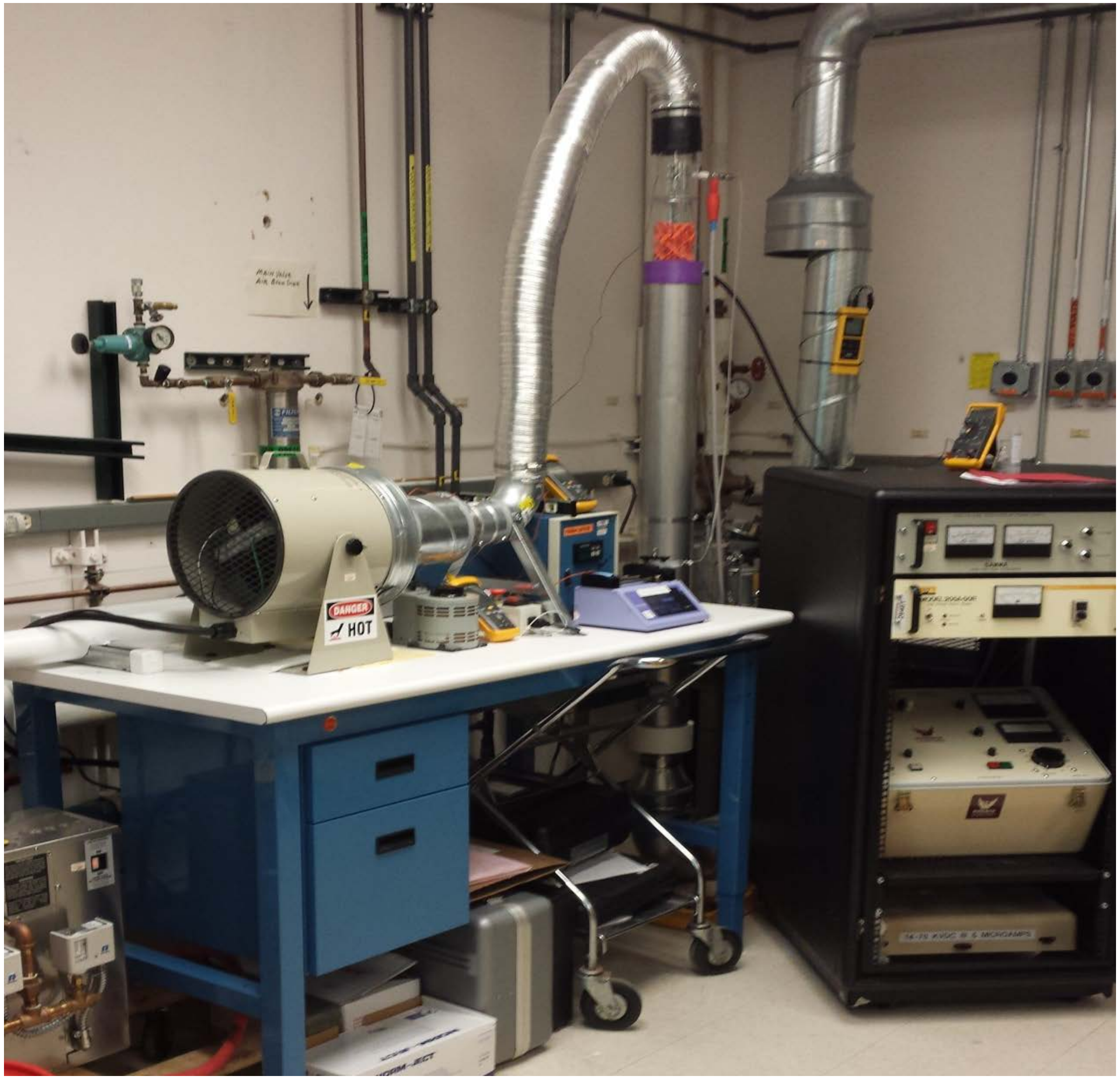
Awards/Recognition: Invention disclosure submitted.

Lessons Learned:

- Greatest improvements in efficiency from 13% (2015) to 50% (2016) were achieved through improved precipitator design, nebulizer flow and running the system in the laminar flow regime.

- Technologies to further reduce charged droplet size could lead to further efficiency improvements.

Dryer Simulator Test System Design Phase 1



Dryer Simulator test system

Controls for:

- Steam Input/Humidity level
- Variable speed fan
- Heat Input
- Variable speed fan control
- Syringe pump for Nebulizer feed
- High voltage for Nebulizer
- High Voltage for Precipitator

Instrumentation for:

- Totalized water input to steam generator
- Temperature – multiple points
- Humidity – multiple points
- Pressure – multiple points
- Air Speed
- Total collected water

Approach
Modeling, Design, Experimentation and Prototyping

Air speed monitoring

Phase 1 Lessons Learned: Efficiency Drivers and limitations

Factors driving efficiency:

Smaller higher charged droplets- droplet size/charge

- Limited due to clogging (110um diameter)

Increased density of smaller charged droplets (nebulizer flow)

- Limited due to pressure and number of nozzles

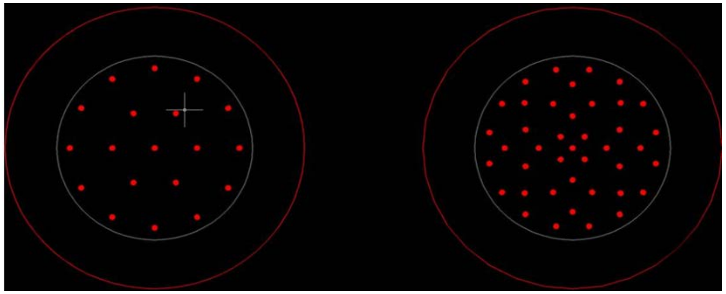
Optimized ESP heat rejection

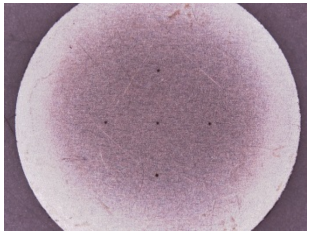
- Limited by passive exchanger design area

Laminar flow

- Minimum limit determined balanced with heat rate input

19 and 41 hole “shower head patterns





Laser Drilled 5 hole Kovar plate

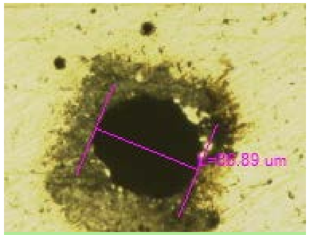
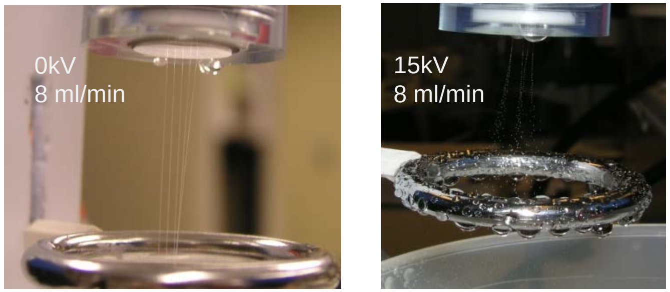


Image of laser drilled hole in Kovar at ~86um



Left, 5 hole Kovar disc, no voltage applied, right, 15kV voltage applied

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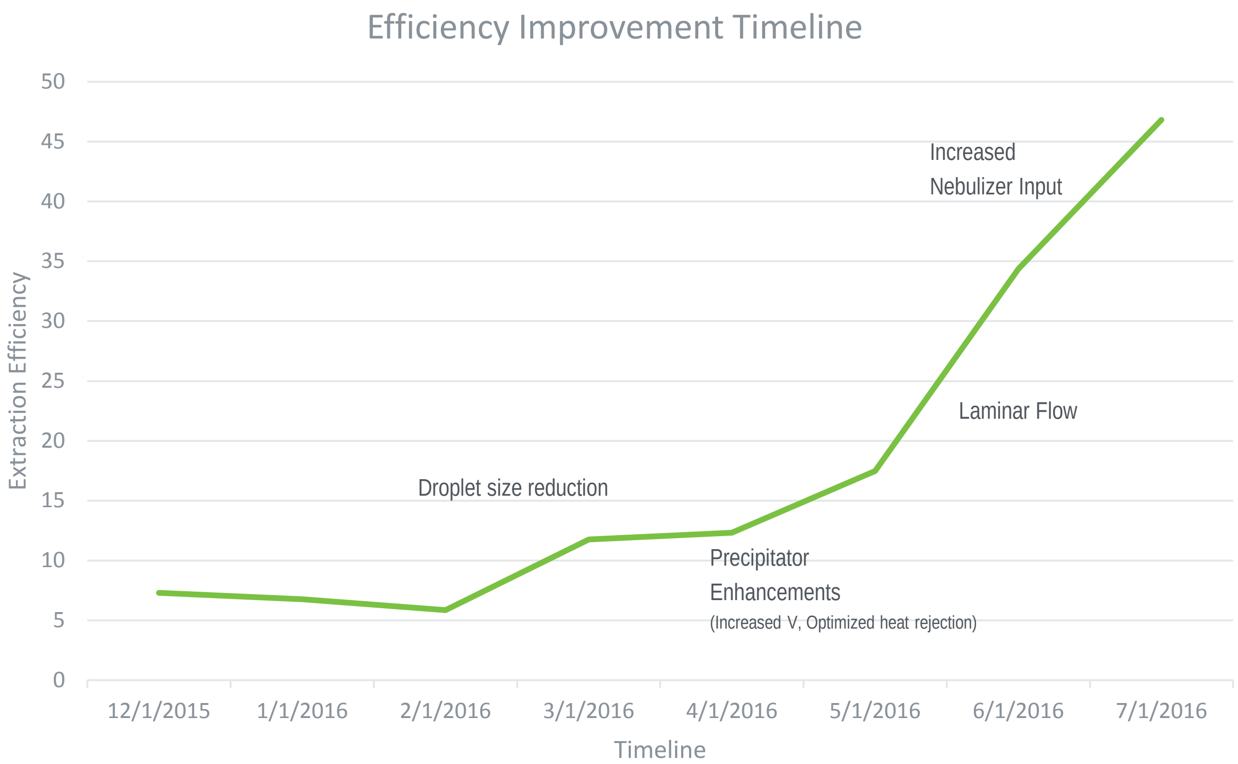
Efficiency Improvement Timeline



- Laminar flow and increased Nebulizer input are the main drivers of efficiency
- IR Steam rejection rate will be critical to maintaining 1hr drying time

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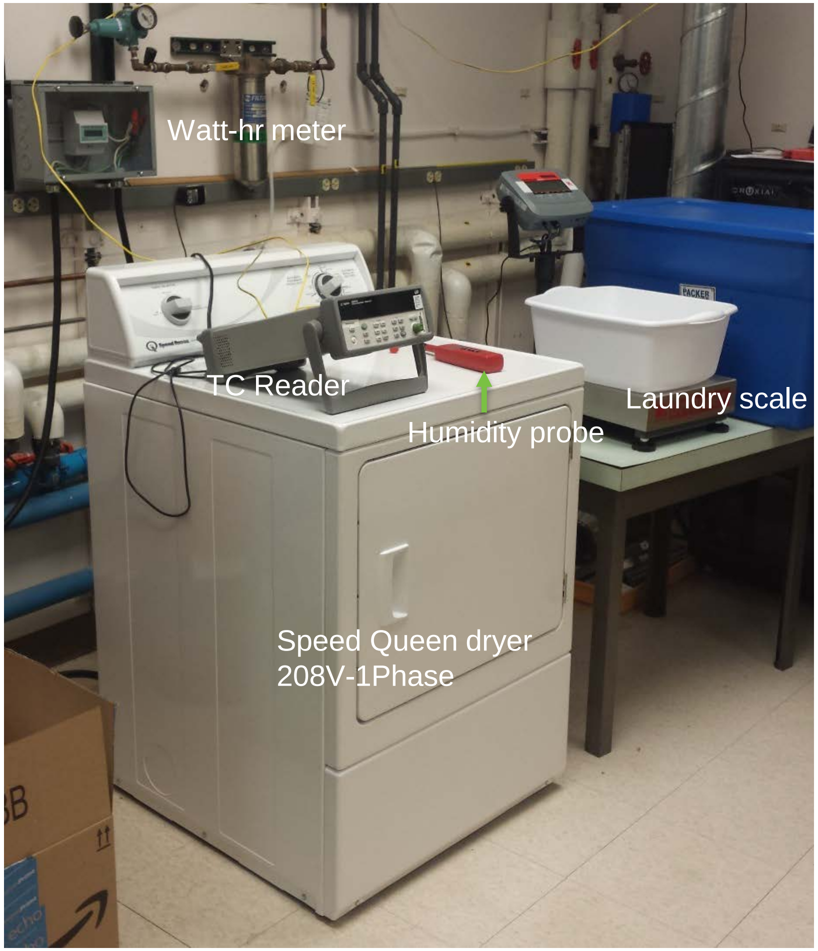
Phase 2 Dryer Prototyping

Dryer selection
- Manual, analog controls
- Timed dry and humidity sensing drying
- Stainless steel drum or polished metal drum
- No glass door
- 208V single phase operation
- Fixed back drum

Choice – Speed Queen electric dryer



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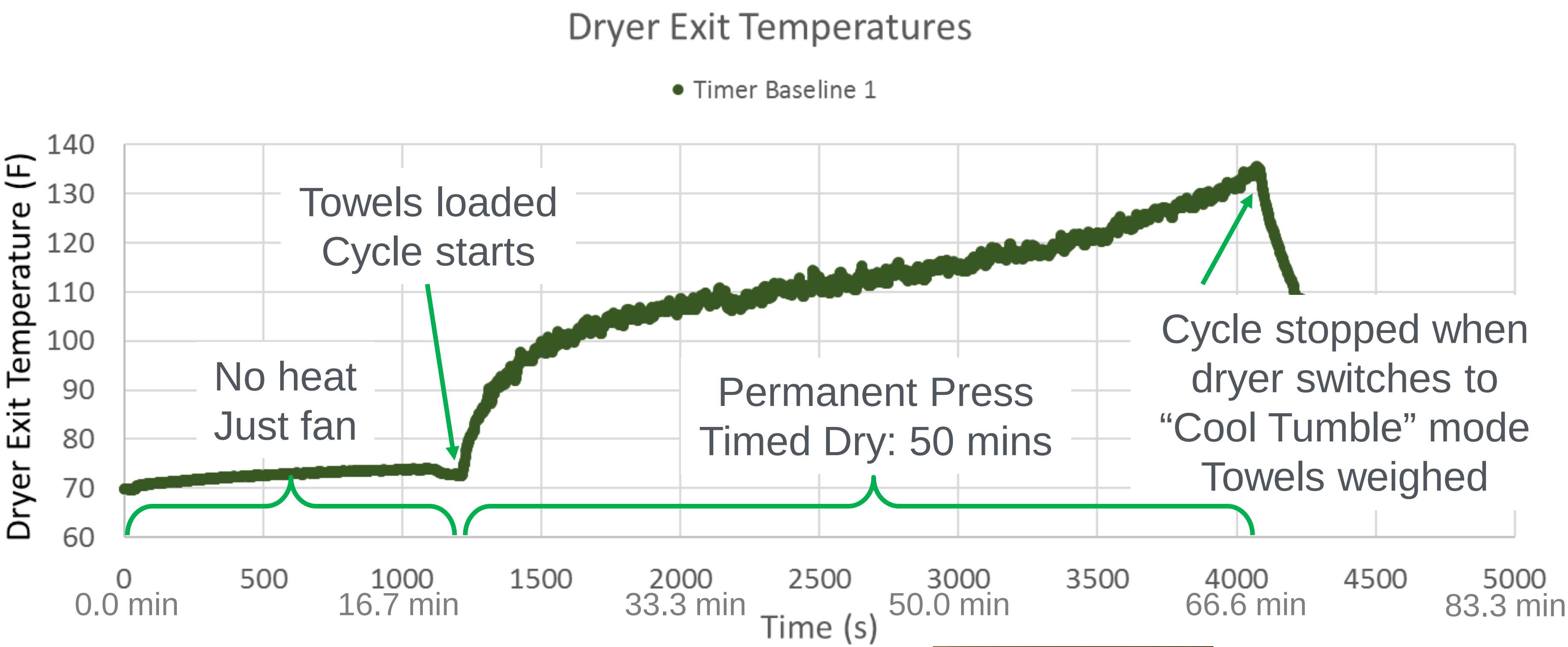
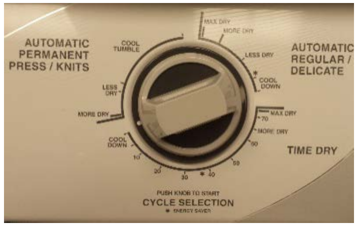
Dryer Baseline Procedure

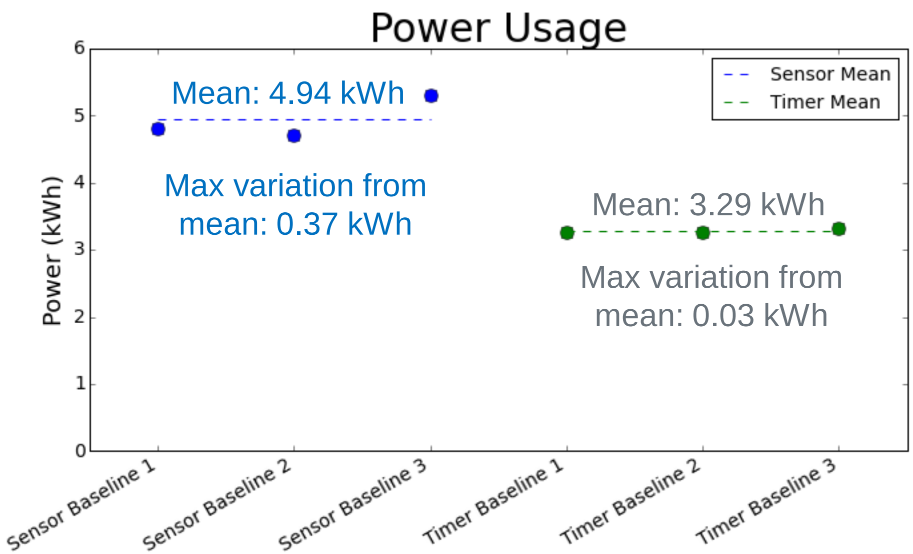


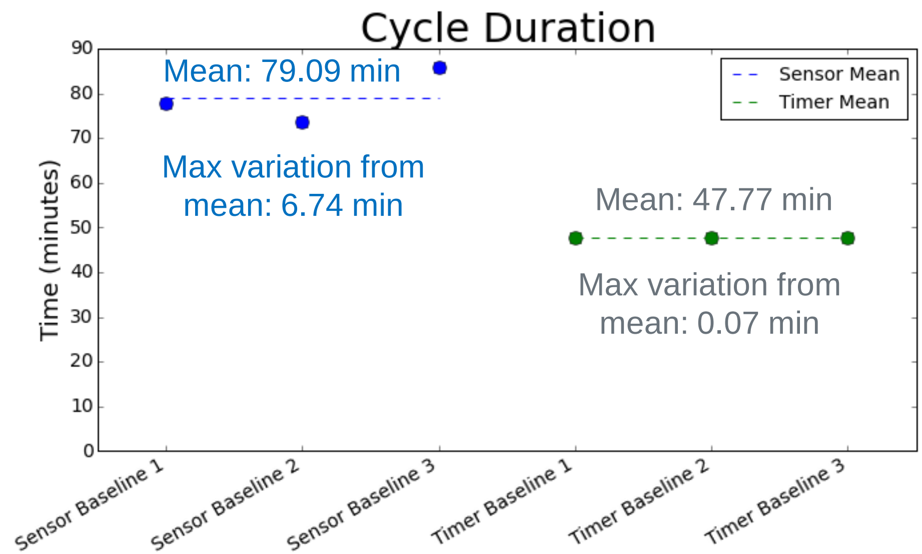


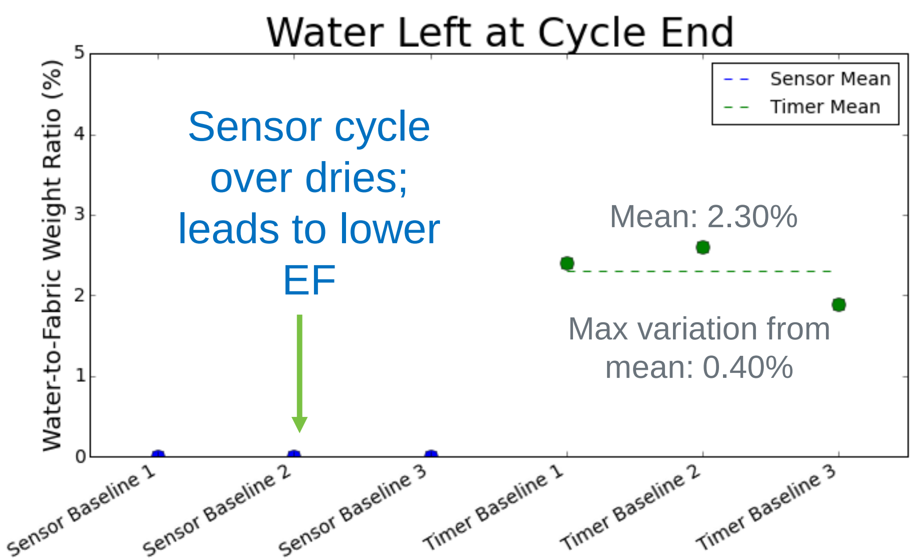
- Three baseline runs each:
- “Sensor”: Permanent press, automatic “Less Dry”
- “Timer”: Permanent press, timed dry 50 mins
- 7.8 lbs white cotton towels + 5.0 lbs water = 65% water/fabric ratio

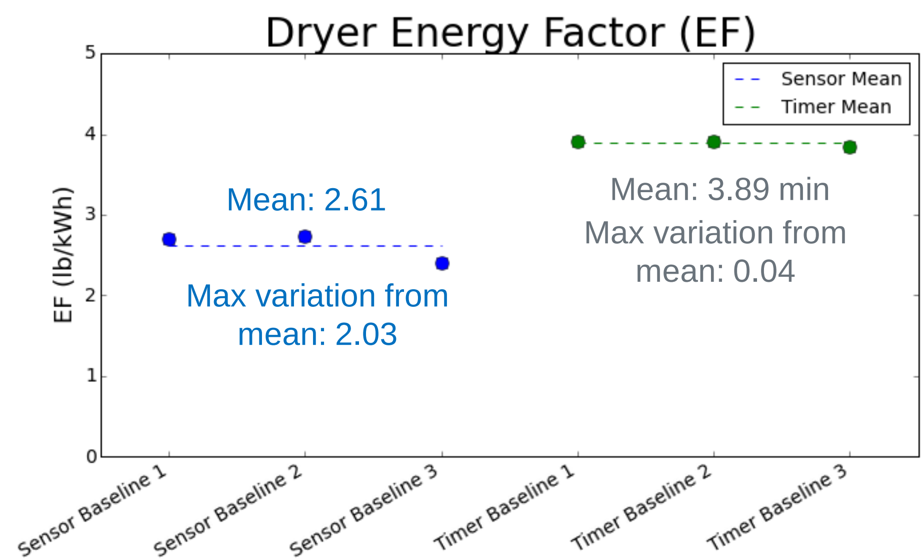
Dryer Baseline Data

"Sensor": Automatic Permanent Press, Less Dry
"Timer": Timed Dry, 50 min



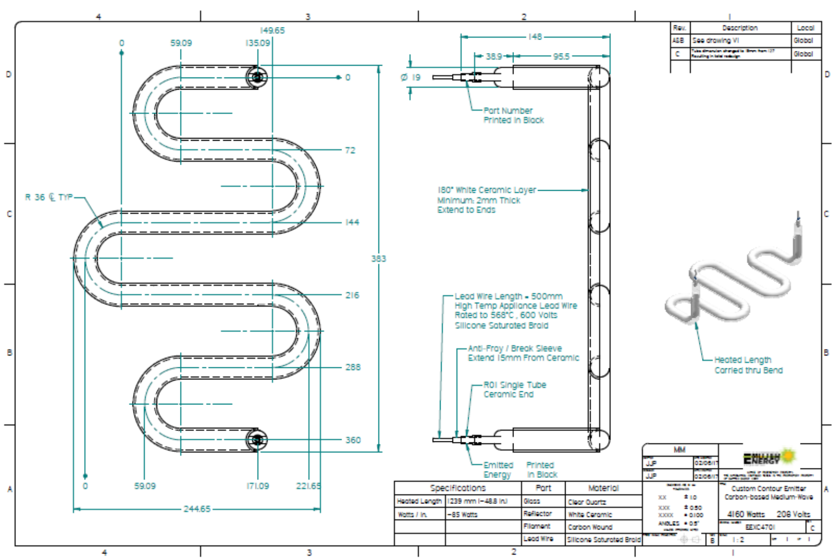




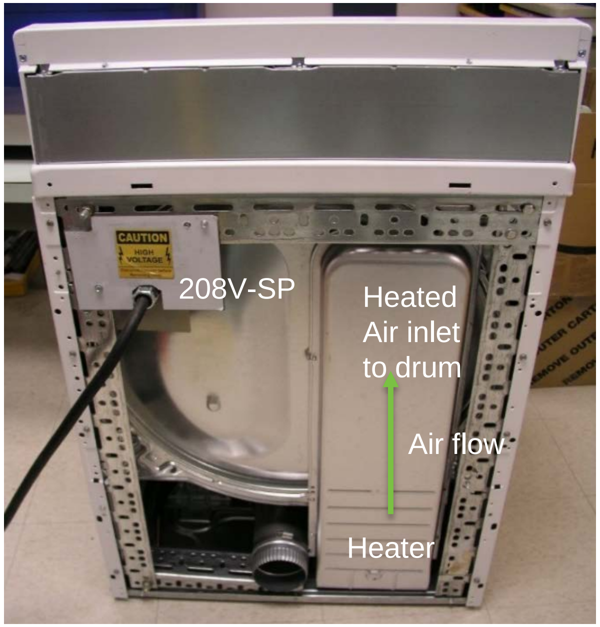


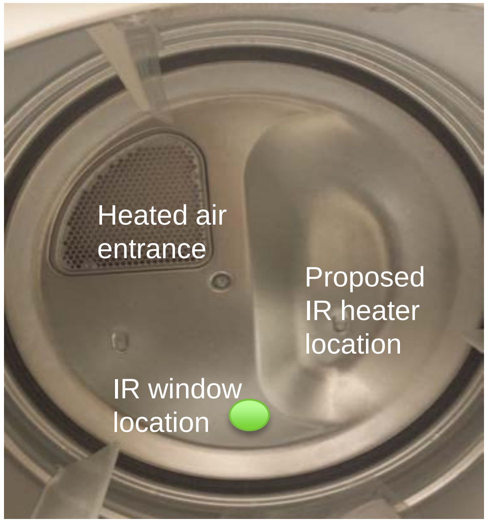
Dryer Prototype Modifications

- Structural modifications necessary
- Custom IR heater to be located with in depressed area on fixed back drum
- Targeting ~5000W, mid IR 2-5um
- Carbon filament, White ceramic reflector
- Quartz cover plate facing interior of drum to prevent scorching of clothes
- Soft start required for longevity
- Sapphire IR camera viewing window to be located at green circle.



Rev2 Custom IR Heater





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IR Heater Control – Two pronged Approach

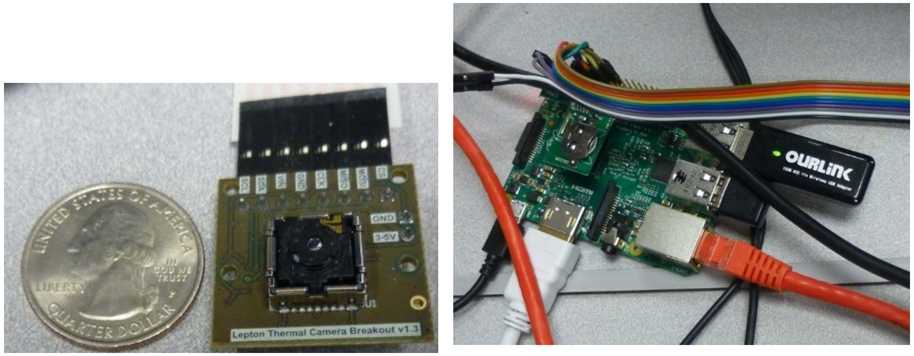
Control Approaches

- TC control from exhaust temperature
  - Lumped average
- IR camera control
  - Moving average of tumbling clothes
  - Identify and adjust for hot spots

Power Controller for IR heater

- Eurotherm 3216 PID controller
  - Universal inputs
    - TC, RTD, mV, mA, CT
- Eurotherm 32A Epack
  - Compact SCR power controller
  - >6500W capability
  - Soft start capable

Eurotherm Controller and Epack driver



Low cost IR Camera and Raspberry Pi processor

Project Integration and Collaboration

Project Integration: The project staff routinely collaborates with internal "GE Experts" and BDM's to accelerate development.

Partners, Subcontractors, and Collaborators: DOE

Communications: NA to date. Research publications to follow.

Next Steps and Future Plans

Integrate IR heaters into dryer

- Instrument temperature monitoring and over- temperature shutdown
- Measurement of drying time and power consumed
  - Compare to baseline (expect 30% less energy usage)

Modify dryer blower motor or install separate motor for airflow control

- Achieve laminar flow
- Test IR operation at laminar flow
- Compare energy use to baseline (expect 30% less energy usage)
- Compare time to dry at laminar flow

Integrate Nebulizer/Precipitator with IR dryer prototype

- Demonstrate MVP prototype operation at an EF >4.04

Pursue technology licensing opportunities through GE Ventures

REFERENCE SLIDES

Project Budget

Project Budget: DOE $1,040,040, Cost share $257,915
Variances: No cost extension, moving project completion to 9/30/2017
Cost to Date: $732,393
Additional Funding: NA

Budget History					
Start Date –10/1/2014 (past)		FY 2016 (current)		FY 9/30/2017 –End Date (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
125,461	31,365	585,914	146,478	1,040,040	257,915

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Project Plan and Schedule

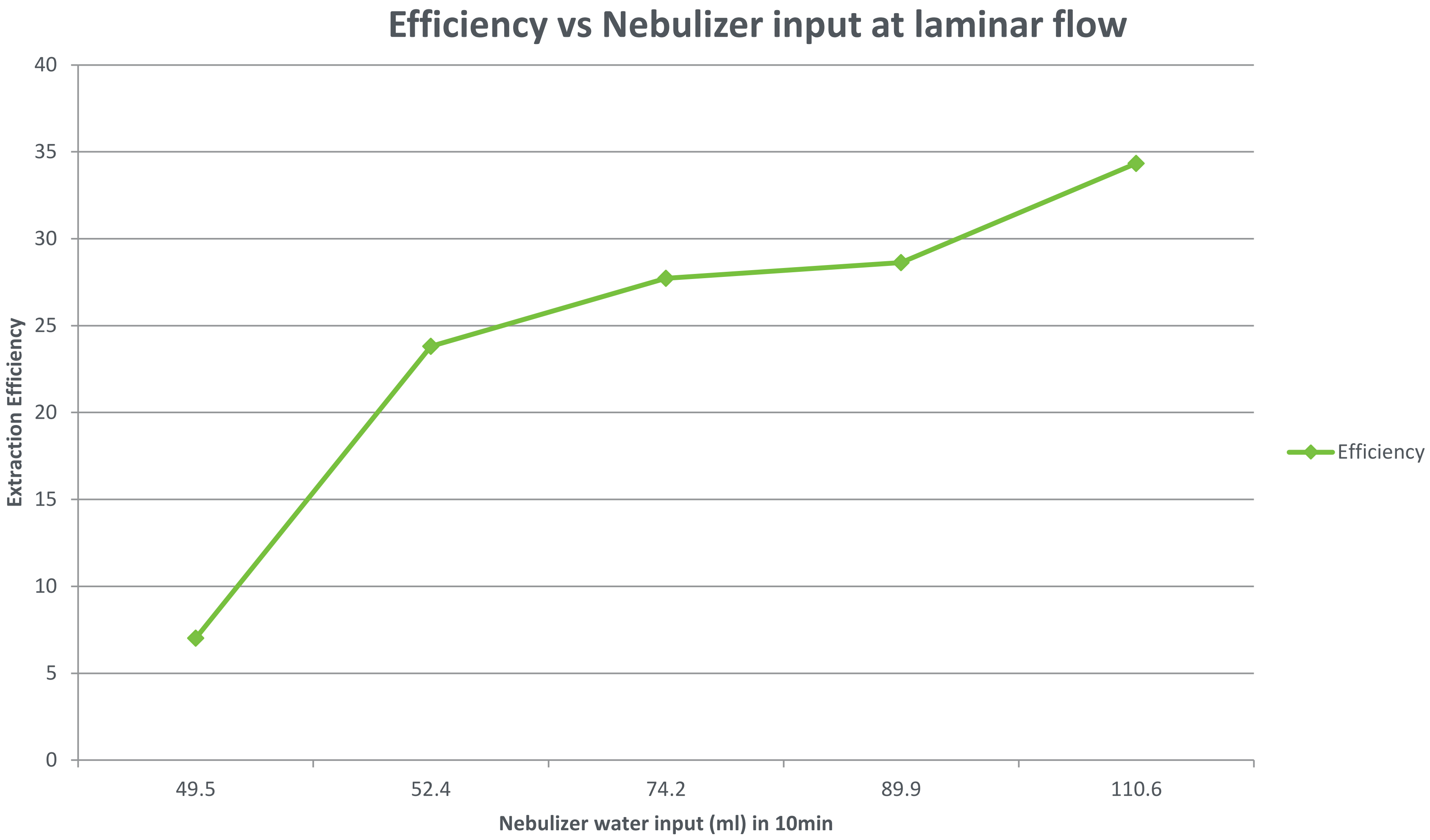
- Project origination date 10/1/2014, Completion date 9/30/2017
- First Go/No-Go Milestones met 6/31/2016 – Demonstration of ~50% extraction efficiency
- 6 Month no cost extension granted

Milestone summary table.

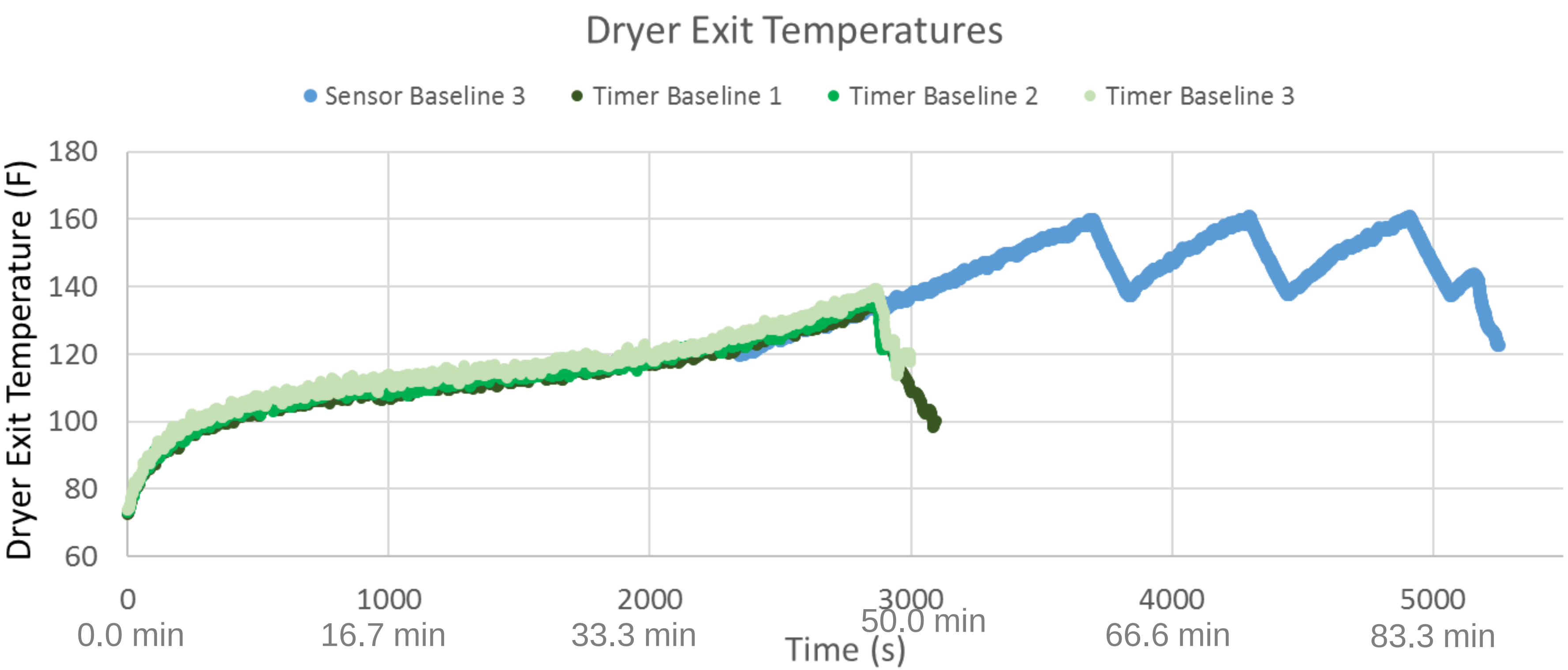
Recipient Name: GE Global Research Project Title: Energy Efficient Clothes dryer with IR Heating and ESP						
Task	**Milestone Type**	**Milestone Number**	**Milestone Description**	**Milestone Verification Process**	**Anticipated Date**	**Anticipated Quarter**
1.Dryer System Level Design	Milestone	M1.0	Report summarizing the dryer design and required subcomponent performances to exceed an EF of 4.04	Report submitted to DOE	3	1
2. Design and Testing of the ESP and Exchanger	Milestone	M2.1	Demonstration of an ESP meeting the system Subtask1.1 requirements	Measured results from ESP testing	12	4
2. Design and Testing of the ESP and Exchanger	Milestone	M2.2	Report summarizing the ESP design and performance	Report submitted to DOE	21	7
2. Design and Testing of the ESP and Exchanger	Go/No-Go 1 No-End Program	Go/No-Go 1	Measured efficiency of the ESP must meet system requirements from Subtask 1.1	Measured results from the ESP testing	21	7
3.Design and Testing of the IR heater system	Milestone	M3.1	Demonstration of IR dryer assembly meeting requirements of Subtask 1.2	Measured results from the IR dryer testing	27	9
3.Design and Testing of the IR heater system	Milestone	M3.2	Report summarizing the IR heater design and performance	Report submitted to DOE	27	9
4. Integration, testing and optimization of the IR/ESP clothes dryer	Milestone	M4.1	Demonstration of integrated dryer exceeding 4.04 EF	Measured results of integrated dryer testing	33	11
4. Integration, testing and optimization of the IR/ESP clothes dryer	Milestone	M4.2	Report summarizing the integrated dryer performance	Report submitted to DOE	33	11
5. Technology to Market Strategy Plan and Commercialization	Milestone	M5.1	1.Develop a detailed market strategy and commercialization plan with a market analysis of potential sales and an evaluation of potential US jobs created by commercialization. A target range for total system cost will be identified.	Report submitted to DOE	33	11
5. Technology to Market Strategy Plan and Commercialization	Milestone	M5.2	2.Identify potential US manufacturers of required system components.	Report submitted to DOE	33	11

Back up slides

Efficiency vs Nebulizer input at laminar flow



Dryer Baseline Data: Temperature History



Lessons learned:

- Dryer is temperature limited at ~160F; goes into pulse mode after limit reached
- Sensor mode, even on “less dry”, over-dries and lowers EF
- Timed dry is fairly repeatable with respect to time and temperature

2017 BTO Peer Review - Presentation Instructions

(not a template slide – for informational purposes only)

- **Presentation Submission Requirements:**
  - MS PowerPoint format
  - Size Limit: 15 MB (prefer smaller file)
  - Due Date: Monday, February 27, 2017
  - Submit via email to BTOPeerReview@ee.doe.gov
  - Name your electronic MS PowerPoint presentation file as follows (use the first 4 letters of your title): [Title_Organization_LastName.ppt]

- **NOTE:** We will send your presentations to reviewers prior to the meeting. To provide adequate time for the reviewers, you **MUST** submit your presentation by **Midnight (EDT) on February 27, 2017**.
- You may **NOT** bring a different presentation to the event. Reviewers will see the same presentation at the peer review event that they review off-line in advance.