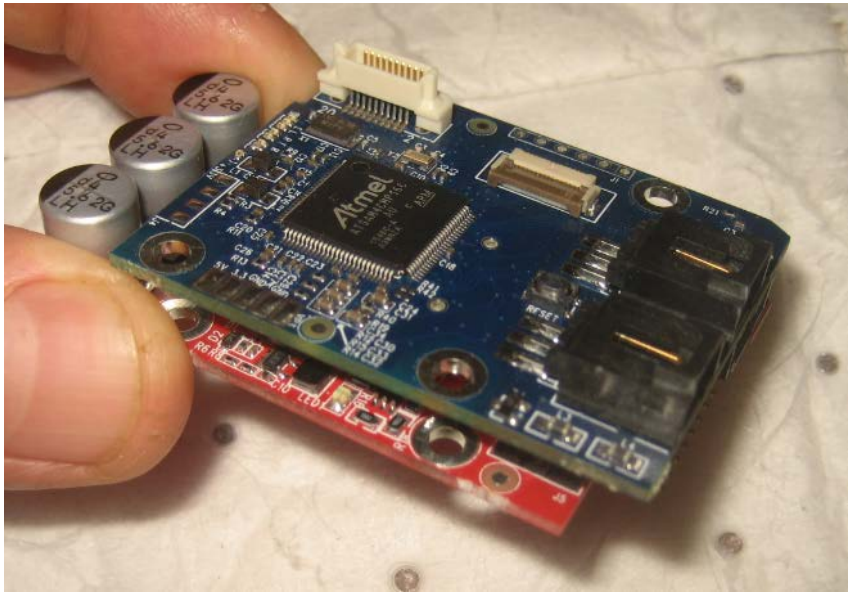
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Low Cost Hardware and Software for Revenue Grade Accuracy Building Sub-metering



Argonne National Lab, Amzur Technologies, 2G Engineering

Theodore Bohn, Principal Electrical Engineer

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Project Summary

Timeline:

Start date: 10/1/2016

Planned end date: 9/30/2018

Key Milestones

1. Preliminary design requirements defined; 9/30/2017
2. Release of functional beta (99.8% accuracy) three phase submeter, for field trials; 5/31/2018
3. NTEP Accuracy certification testing completed; 9/1/2018

Key Partners:

Amzur Technologies- Software
2G Engineering- Hardware/Firmware

Budget:

Total Project $ to Date:

- DOE: $1000k
- Cost Share: $0

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Project Outcome:

Develop a revenue-grade sub-metering solution for all reasonably sized (<480vac, <200A) building equipment, systems, and loads at minimized net cost of installed system that will enable monitoring-based commissioning to optimize building operations.

Team

ANL: Ted Bohn; Principal Investigator, Electrical Engineer
Ralph Muehleisen; Principal Building Scientist

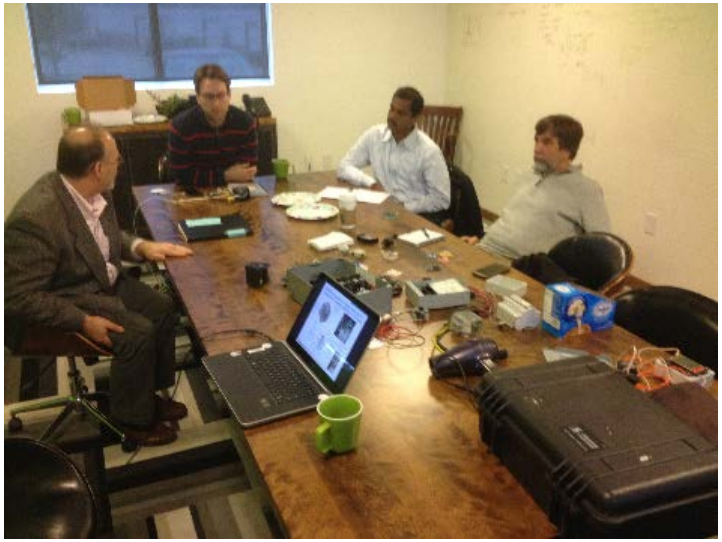
2G Engineering: **Hardware/Firmware Developer, Mfg. contractor**
(Sun Prairie, WI) Hal Glenn; President/Co-owner
Josh Lange; Software-design engineer

Amzur Technologies: End Use Dashboard, Analytics Development
(Tampa, FL) Raymond Kaiser; Director, Energy Management Systems
Shankar Piriya; Software Products Developer

ANL team has expertise in the buildings sector as well as ability to complete benchmark assessments of components, systems and in-situ meter performance.

Amzur currently produces submeter analytics and user interface software for their clients.

2G Engineering is a full service design engineering-fabrication firm with contract manufacturing and distribution capabilities.
They have produced 4 prior submeter series for ANL.



Challenge

- Electric sub-metering for multi-unit dwelling and commercial spaces is often implemented with multiple premise meters, leading to high installed meter costs.
- Present available options for purpose built submeters are most often either over-featured/over-priced or under-performing at a more modest price.
- Certified meter accuracy requirements for commercial applications that meet upcoming Weights and Measures compliance are undefined; unenforced today.
- Current sensors are often bulky and expensive, leading to over-crowded load center installations when many sensors are used, with possible electrical safety issues.
- Network connectivity of meters to end location of data and analytics software are often complicated and expensive to install as well as properly commission.

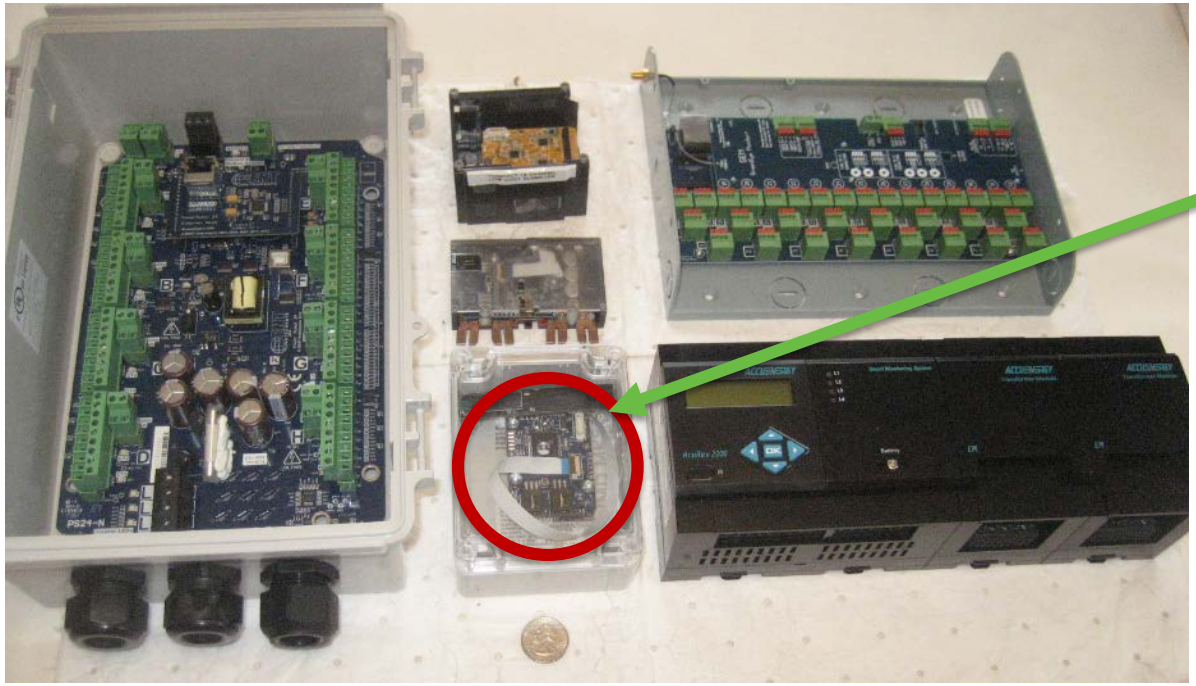
Approach

- Comprehensive review/benchmark of current electric submeter hardware and software products.
- Early project interviews provided stakeholder engagement for both input on minimum viable product (MVP) features as well as end-user feedback on prototype meters, software and installation procedures/documentation.
- Interviews revealed that total installed system cost including hardware, software, labor, and cost implications of interruption of electrical service during installation were as important as initial hardware costs.
- Two tiered approach used to reduce submeter measurement hardware size and cost
  - Atmel SAM4CM System-on-Chip (SoC) metrology on mains (3) measurements
  - ST Micro STPM32 lower cost SoC metrology for parallel (18) channels ($0.50 per channel of metrology).
- A 'software defined metering' tool set was implemented to allow a common measurement platform to be configurable as a single, polyphase, or multi channel AC(and DC) submeter product.
- Flexibility on packaging this compact meter can lead to further installed cost savings.

Approach

Dashboard/analytics software for this project covers three core use cases:

- **Multi-family dwellings** – display aggregate building load and load by tenant by hour, week, month, year and user-selected time periods.
- **Building load by load type**. Provide load by (circuit) load type (HVAC, lighting, DHW, pumps & motors, and plug loads) by hour, week, month, year; selectable
- **Building Portfolio** – for campuses, districts, and property portfolios provide energy tracking by building type, load type within and across buildings, and support performance benchmarks by user-select criteria. Support alerts, alarms, and notifications based on user-defined thresholds and triggers.



Comparison of ANL Compact Submeter (in center, 1.5”x2”) to other $1000+ submeters; Dent PowerScout 24 (left), GreenEye Monitor (upper right), AccuRev2020-2D (right)

{A quarter is shown below for scale}

Impact

- A **figure of merit** for a building load measurement electric submeter is the net installed cost, divided by the number of branch circuits/individual loads measured by the meter.
  - As the cost of the metering electronics is reduced, the (now fixed) price of the current sensor used for each branch load becomes a more significant percentage per channel.
- Software defined metering can enable economies of scale to use the same (compact) metering hardware, configurable for a wide range of applications.
  - The SoC metrology solution implemented can use a spectrum of current sensor types and current ranges; both conventional current transformer (CTs) as well as Rogowski, shunt and next generation flux gate type sensors.
  - This flexibility can help meet the specific cost targets (<$15/channel component target costs) as well as help reduce installation labor costs with software tools that allow faster, (automated) commissioning.
- Enable monitoring-based commissioning and contribute to BTO goal of enabling energy savings from automated fault detection and diagnostics through cost-effective sub-metering.
- Field trials and initial manufacturing cost studies indicate that this type of software defined meter that leverages economies of scale on a standard metrology platform can achieve these cost targets in constrained use case electric sub-metering scenarios.

Progress

This electric submeter project has been funded at $500k in both FY17 and FY18 for $1000k total. With 25% of the project span remaining (2 quarters), $767k has been encumbered as contracts with project partners (Amzur, 2G Engineering), hardware costs or ANL effort/travel. The remaining $233k is expected to cover the last of project milestones and reporting tasks.

Q1 Baseline Requirements

- Compiled comparison table of existing submeter product features, cost (if obtainable) and physical size/accuracy.
- Identified over 130 brands. Separated into capability and application types of meters.

Q2 2000hrs durability testing

- Stationary testing of similar (previous vehicle charging application, ANL designed) submeter on cycling load for 2000+ hrs
- No failures or loss of data/accuracy drift
- 15,200 hrs testing as of 4/18/2018
- Evaluated lab capabilities on vibration, thermal shock and grid emulation testing.

Progress

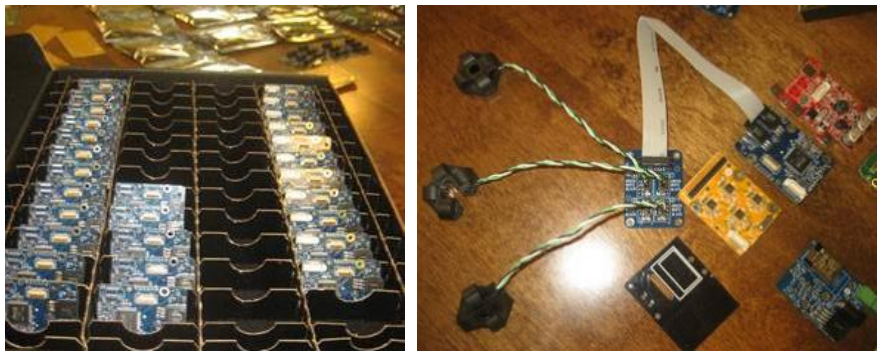
Q3 Current sensor bench tests

- Compiled table of current sensor prices and pro/con aspects of each type of sensor.
- Key tradeoffs include cost vs accuracy, linearity, repeatability, stability over time.
- Installation cost tradeoffs on spit vs solid core sensors and total installed mass.
- Different types of sensors required for AC and/or DC current measurements; active and passive types of sensors (powered?)

Side-by-side photo of lower cost CT and Rogowski sensors

Q4 Go/no-go on cost-accuracy

- Initial goals based on single phase submeter prototypes (<$15/channel, 99% accuracy;)
- 30 single phase metrology electronics boards were fabricated and deployed in a field trial in residential/commercial locations.
- Installation process (required time, unexpected obstacles) was documented as part of cost analysis for total installed cost, and ability to meet hardware and labor cost targets. Focus on drop in package formats.

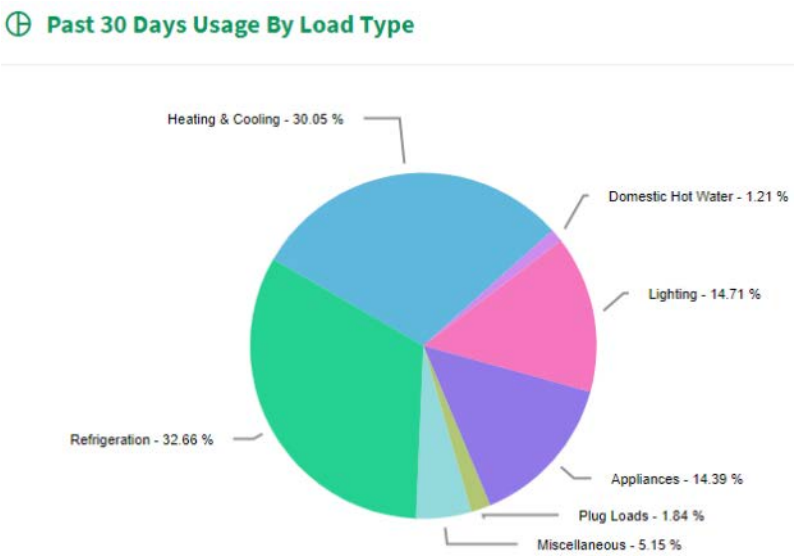


Batch of 30 submeter metrology sub-assemblies used in the 'software defined metering' approach

Progress

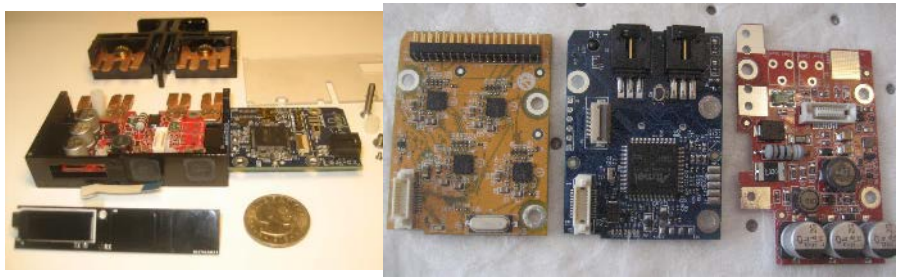
Q5 Demonstrate Software Beta

- Demonstrate functional beta version of Amzur user interface software, with power/energy on multiple meter inputs
- Field trial meters at Historic Green Village (FL), 2G Engineering facility (WI), Residence (WI) and ANL (bench) connected to Amzur dashboard software via network/cloud.
- Software ported to grid edge computing.



Q6 Beta of 3 phase submeter

- Release 3 phase input, configurable submeter design for field trial evaluation
- Task is slightly behind schedule with design iteration {5/31/18 estimated completion}
- Leveraging insights gathered from single phase/DC versions of submeter concerning connectors and mechanical packaging.
- Current sensor flexibility, configuration software and commissioning processes are active submeter evolution areas.
- (Software defined) configurable function modules yields greater product flexibility



Drop-in package; configurable polyphase modules

Stakeholder Engagement

- A new commercial transaction standard is under development by a working group of meter manufacturers, weights and measures (W&M) officials and meter end-users/installers; under the umbrella of the National Conference on Weights and Measures (NCWM). The project P.I. is an active committee member.
- The P.I. of this submeter project is the subcommittee chair on technical requirements to evaluate submeter accuracy for non-utility owned commercial usage (NIST Handbook 44-3.xx). This working group is a natural forum for interaction end users, W&M experts and other manufactures on the present and future needs on submeter products/software.
- The EMerge Alliance formed a new DC meter standard working group in 2016 that engages stakeholders in DC energy distribution applications. Results from ANL benchmark testing of available DC meters is used for baseline DC meter specifications in this group.
- Several peer review meetings were hosted by ANL with metering/sensor/end user subject matter experts in the beginning and middle of this project.
- Prototype single phase submeters are currently in field trial locations at Historic Green Village (FL), commercial spaces (WI), residential (Madison WI) and at ANL,

Remaining Project Work

Future project work includes the following:

- The three phase (software defined/configurable) meter hardware is scheduled to be completed this quarter, and following validation testing on the bench, more field trials of this version of the meter platform are planned.
- As a near-final hardware and software product, remaining tasks include refinement of user/installation/configuration documentation, as well as fault diagnostics if the meter fails to properly measure intended loads. The same goes for accuracy type certification under the work-in-progress National Type Evaluation Program (NTEP) label.
- Short term goals are to refine the cost estimates to scale up production of the platform electronics and mechanical packaging as well as current sensor volume scaled costs.
- Longer term goals include exploring follow-on funding opportunities to manufacture and commercialize this family of electric submeters designs.

Thank You

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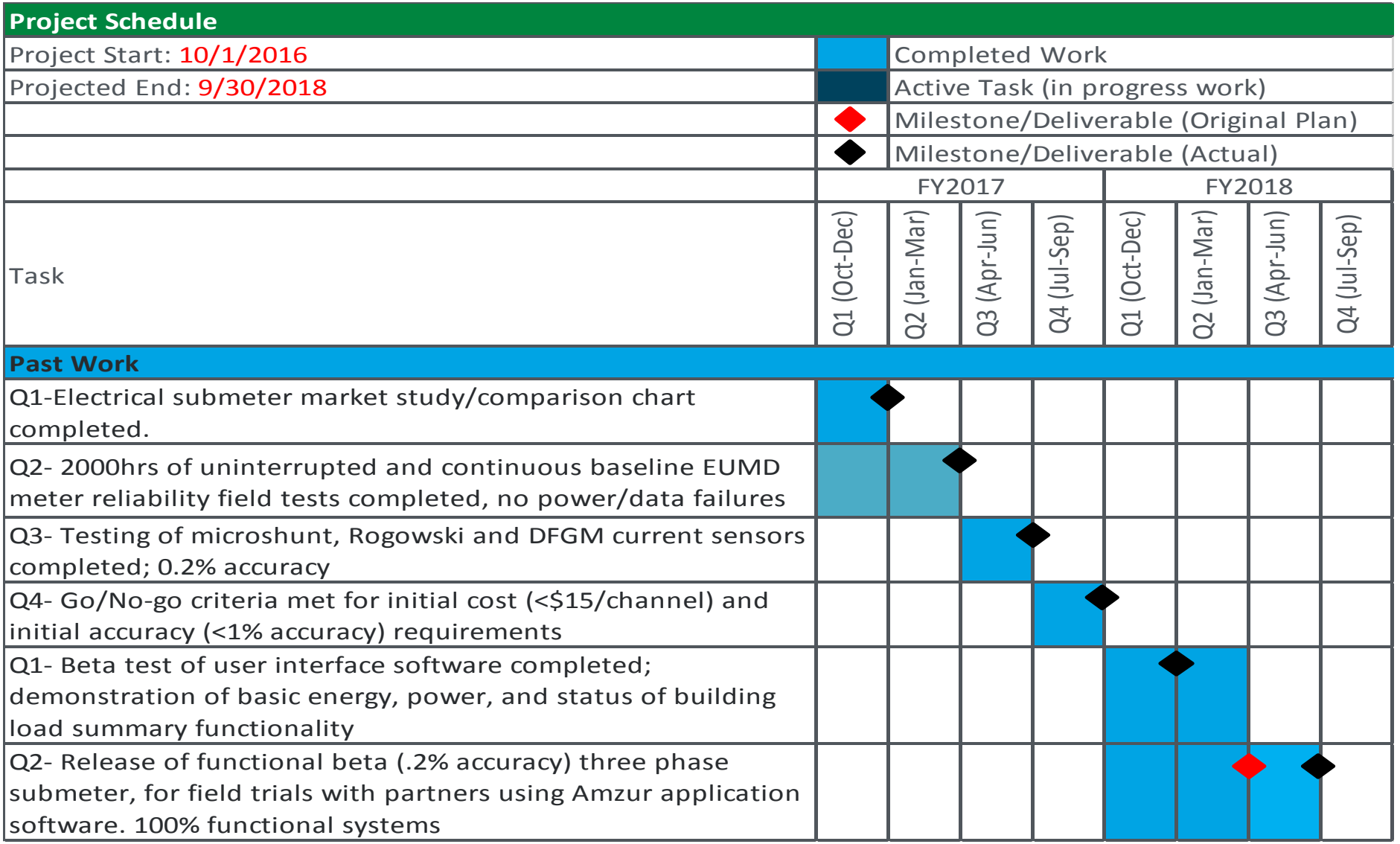
REFERENCE SLIDES

Project Budget

Project Budget: Launched 10/1/16, concluding 9/30/18 with $500k per year for FY17 and FY18 budgeted.
Variances: No variances; full $1000k received;
Cost to Date: $767k of $1000k budget has been encumbered; work-in-progress contracts to partners partially invoiced based on completed work.
Additional Funding: No additional funding sources for FY17-FY18

Budget History					
10/1/16– FY 2017 (past)		FY 2018 (current)		FY 2019 – 9/30/18 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$500k	$0	$500k	$0	$0	$0

Project Plan and Schedule



Project Plan and Schedule

Project Schedule									
Project Start: 10/1/2016		Completed Work							
Projected End: 9/30/2018		Active Task (in progress work)							
	◆	Milestone/Deliverable (Original Plan)							
	◆	Milestone/Deliverable (Actual)							
			FY2017				FY2018			
Task			Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Current/Future Work										
Q3- Full documentation on installation, network connection/commissioning of submeter and online software completed. Peer reviewed as acceptable.									◆	
Q4- CTEP(accuracy) certification testing completed and passed as a final step to a commercialized submeter product										◆

- Milestone for FY18-Q2; Three phase meter implementation slipped from original plan due to issues with system-on-chip metrology implementation and integrating lessons learned/feedback from field trial results on single phase meters
- Ongoing work on documentation and commissioning processes are iterative, incorporating feedback from end-users on draft versions
- Final accuracy certification is tied to availability of NTEP type evaluator and NTEP certificate for this type of meter application (new area for NTEP; provisional certification only at this time.)