



Carbon Neutral Electrical Generation from Human Solid Waste

Developing the Energy Balance and Identifying
Suitable Electrical Generation Solutions Capable
of Harnessing the Thermal Energy

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Outline

- ▶ Our First Pyrolysis Unit
- ▶ The Energy Balance
- ▶ Electrical Generation Solutions
- ▶ Next Generation Units
- ▶ Lessons Learned
- ▶ Next Steps



The First Unit

THE GOAL

- ▶ Off-grid pyrolysis unit
- ▶ Economically viable
- ▶ Treat faecal sludge from 500-10,000 individuals
- ▶ No harmful pollutants, no safety hazards
- ▶ Carbon neutral or negative

एक नया शौचालय, एक नयी सोच

REINVENT · THE · TOILET FAIR

MARCH 2014 • INDIA



Pyrolysis

- ▶ Thermal decomposition of biomass in an environment with a negligible or limited supply of oxygen.
- ▶ Removes pathogens and organic toxins.¹
- ▶ Allows for significant mass reduction (88-95%).
- ▶ Provides a net energy output.²
- ▶ Creates an end usable byproduct, biochar.



India Fair 2014

- ▶ Treat faecal sludge from 2,000 individuals
- ▶ 85% moisture
- ▶ Limited use of supplemental fuel



Energy Balance Assumption

FAECAL SLUDGE

Moisture Content 85%

Energy Content 17.2 MJ/kg

Biochar Output 25.8 MJ/kg

BIOGENIC SUPPLEMENTAL FUEL

Energy Content 16.9 MJ/kg

Moisture Content 5%

Energy Demand

THEORETICAL ENERGY DEMAND

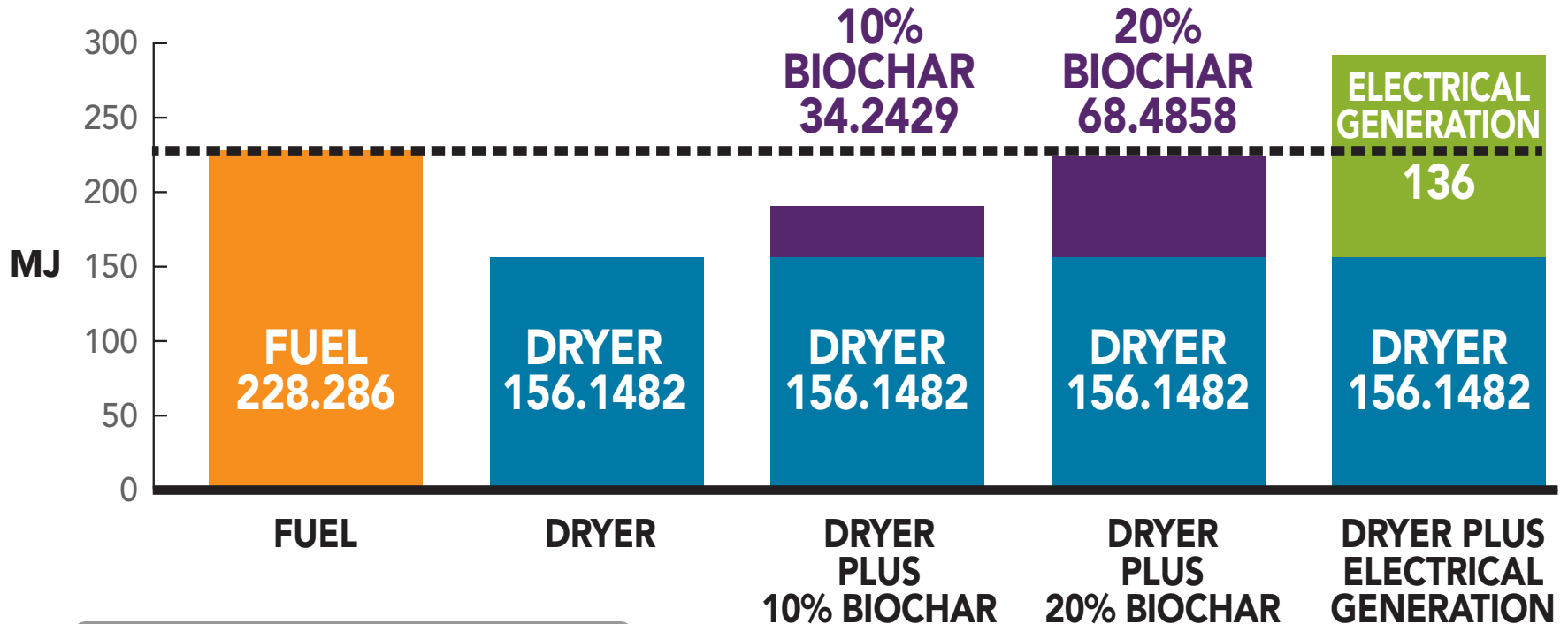
Start-up 3.5 kWe/hr

Steady-state 18 kWe/hr

Shutdown 0.5 kWe/hr

- ▶ **Most electrical components were oversized**
- ▶ **Observational data 3.8 kWe/hr**

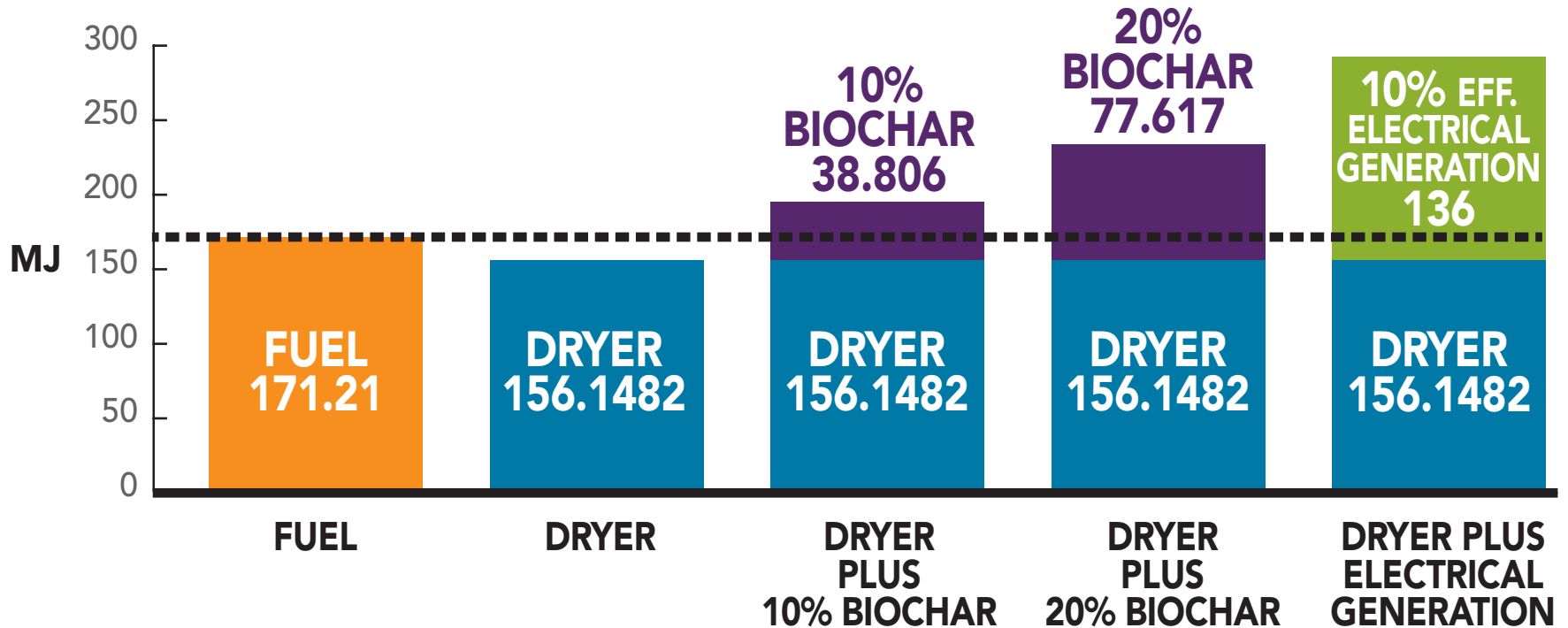
100% Efficiency, 0% Supplemental Fuel



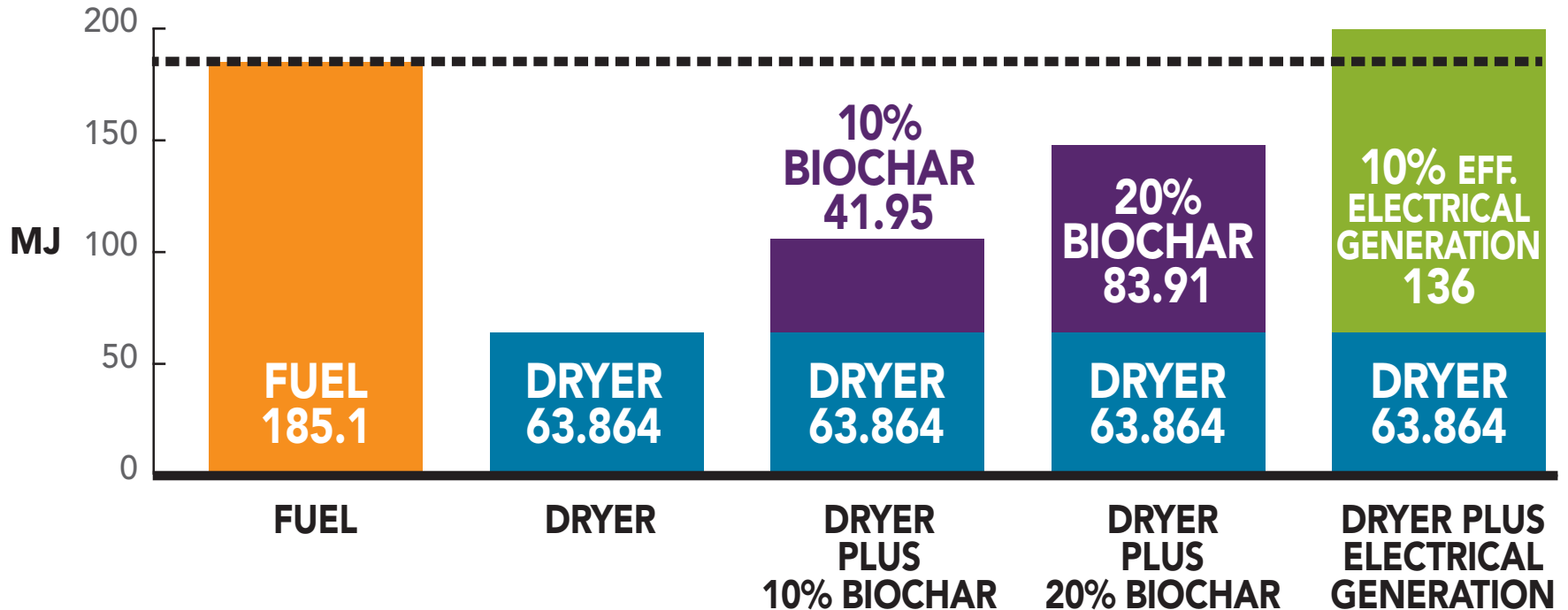
Dryer 96.6 kg/hr
at 85% moisture



75% Efficiency, 0% Supplemental Fuel



75% Efficiency, 15% Supplemental Fuel



Identifying Technology Options

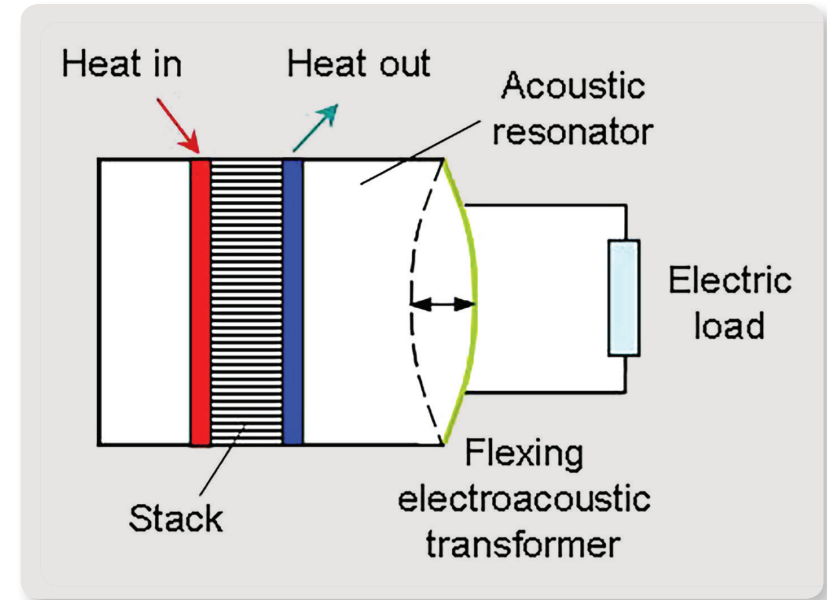
GOAL: IDENTIFY A THERMAL ENGINE THAT COULD GENERATE 3-5 KWE/HR

- ▶ Most thermal generators produce >1 MW/hr.
- ▶ January-March 2016
 - Commercially available
 - Harness waste heat
 - Produce <1 MW/hr
- ▶ Thermoacoustic, Thermoelectric, Stirling, Steam, and Organic Rankine Cycle



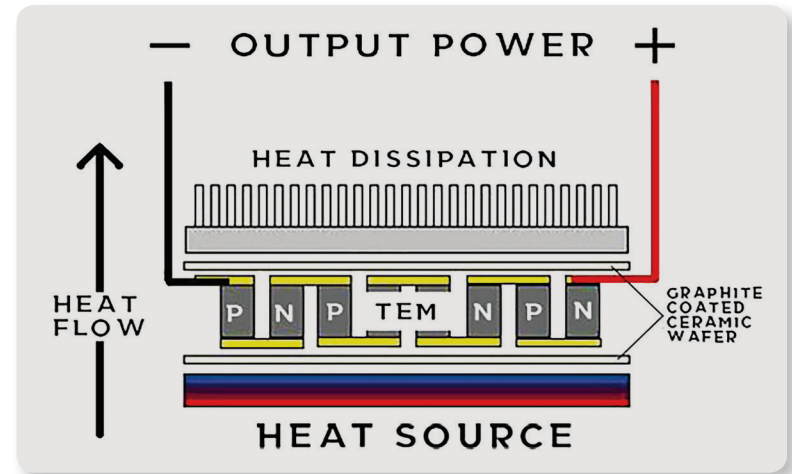
Thermoacoustic Engines

- ▶ No moving parts
- ▶ No annual maintenance
- ▶ High life expectancies
- ▶ Capable of generating 1-5 kWe
- ▶ Three identified manufacturers
- ▶ No products commercially available



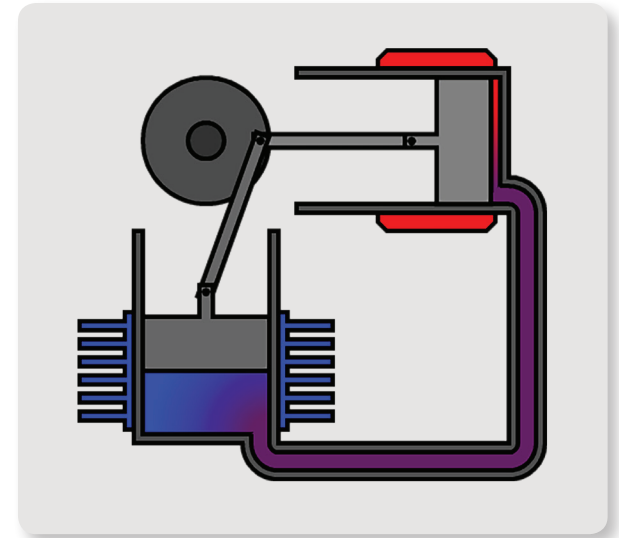
Thermoelectric Generators

- ▶ No moving parts or maintenance
- ▶ Destroyed when overheated (400-450°C)
- ▶ Output: 5-100W
- ▶ Three manufacturers identified
- ▶ Electrical Efficiency: 0.5-5%
- ▶ Price per watt: 7.25-26.00 USD
- ▶ Cannot generate sufficient power



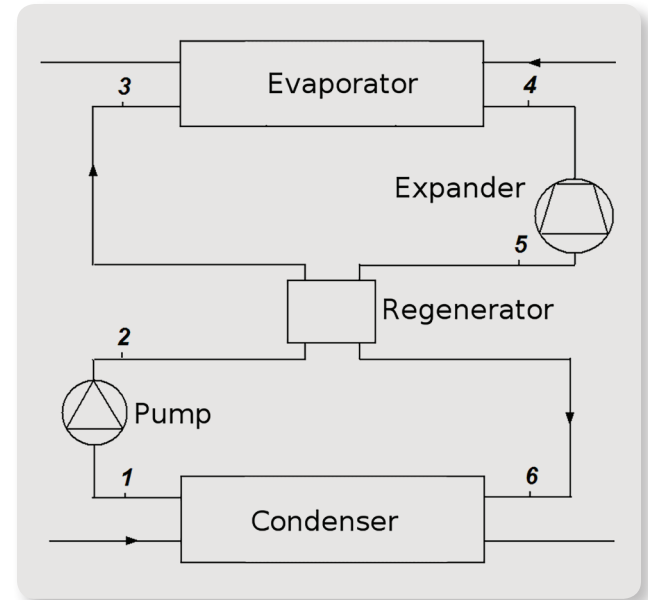
Stirling Engines

- ▶ High efficiency
- ▶ 11 manufacturers identified
- ▶ Output: 0.60-25 kWe
- ▶ Price per watt: 7-30 USD
- ▶ No products commercially available capable of harnessing waste heat



Steam Engines

- ▶ Powered with any heat source
- ▶ 11 manufacturers, 16 products
- ▶ Output: 1.5-18.6 kW_e
- ▶ 10-20% efficiency
- ▶ Price per watt: 1-6 USD
- ▶ Multiple products identified



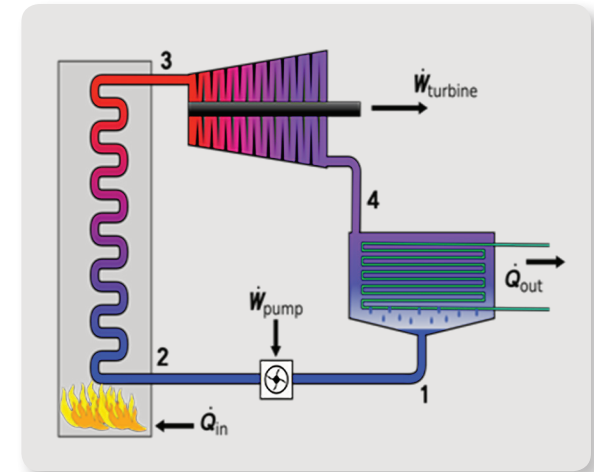
Steam Engine Works™

Quasiturbine.com



Organic Rankine Cycle

- ▶ Capture low temperature heat
- ▶ Long life expectancies
- ▶ Eight manufacturers
- ▶ 9-17% efficiency
- ▶ Less corrosion and mechanical stress
- ▶ Output: 2-800 kWe
- ▶ Price per watt: 4-8 USD
- ▶ Multiple products identified



Thermal Power Generation Summary

Thermoacoustic

Not commercially available

Thermoelectric

Limited generation potential

Stirling

Not commercially available

Steam

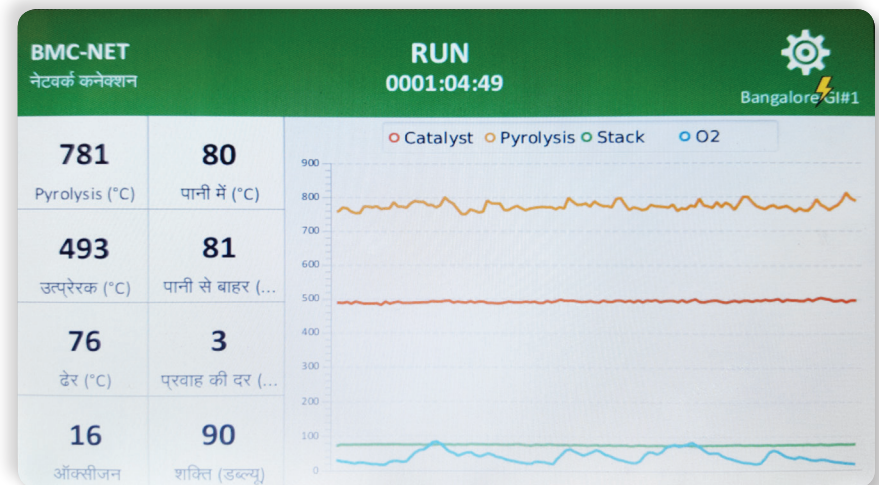
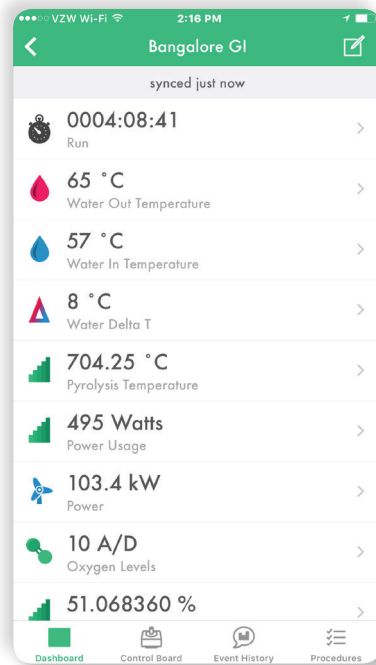
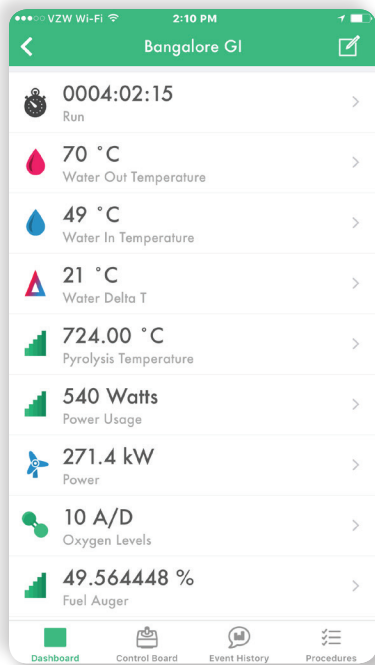
Viable option

Organic Rankine Cycle

Viable option

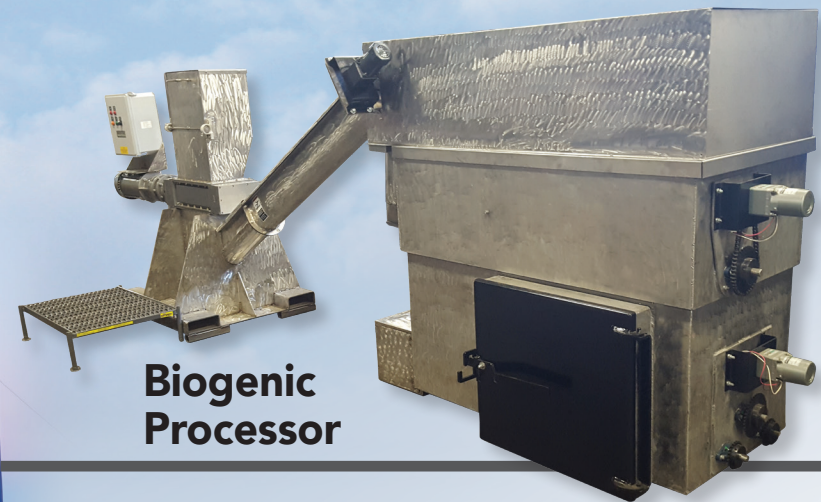
Improving the Energy Balance

- ▶ Improved combustion efficiency (95%)
- ▶ Decreased electrical needs
- ▶ Data, Data, Data



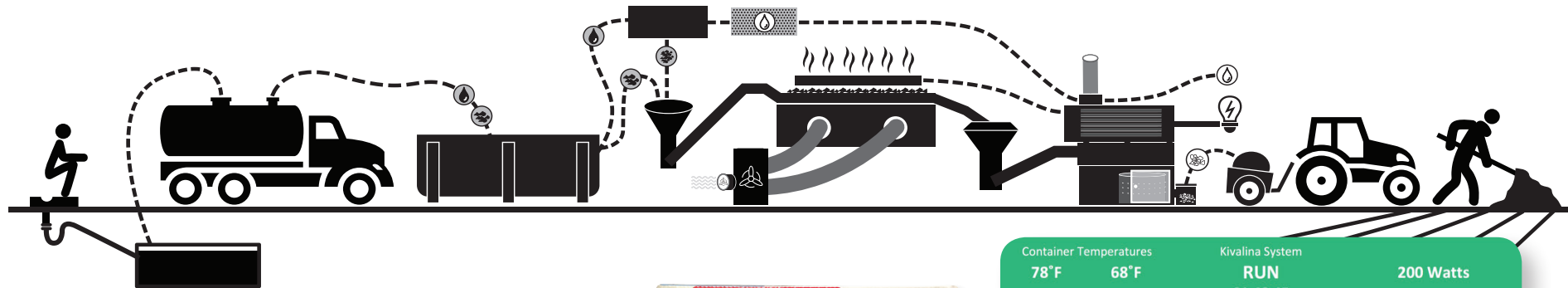
Thermal Power Generation Conclusion

- ▶ Eliminate Dryer
- ▶ Grinder for pre-processing supplemental fuel
- ▶ Smaller Footprint



Lessons Learned

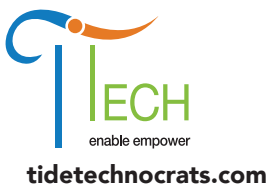
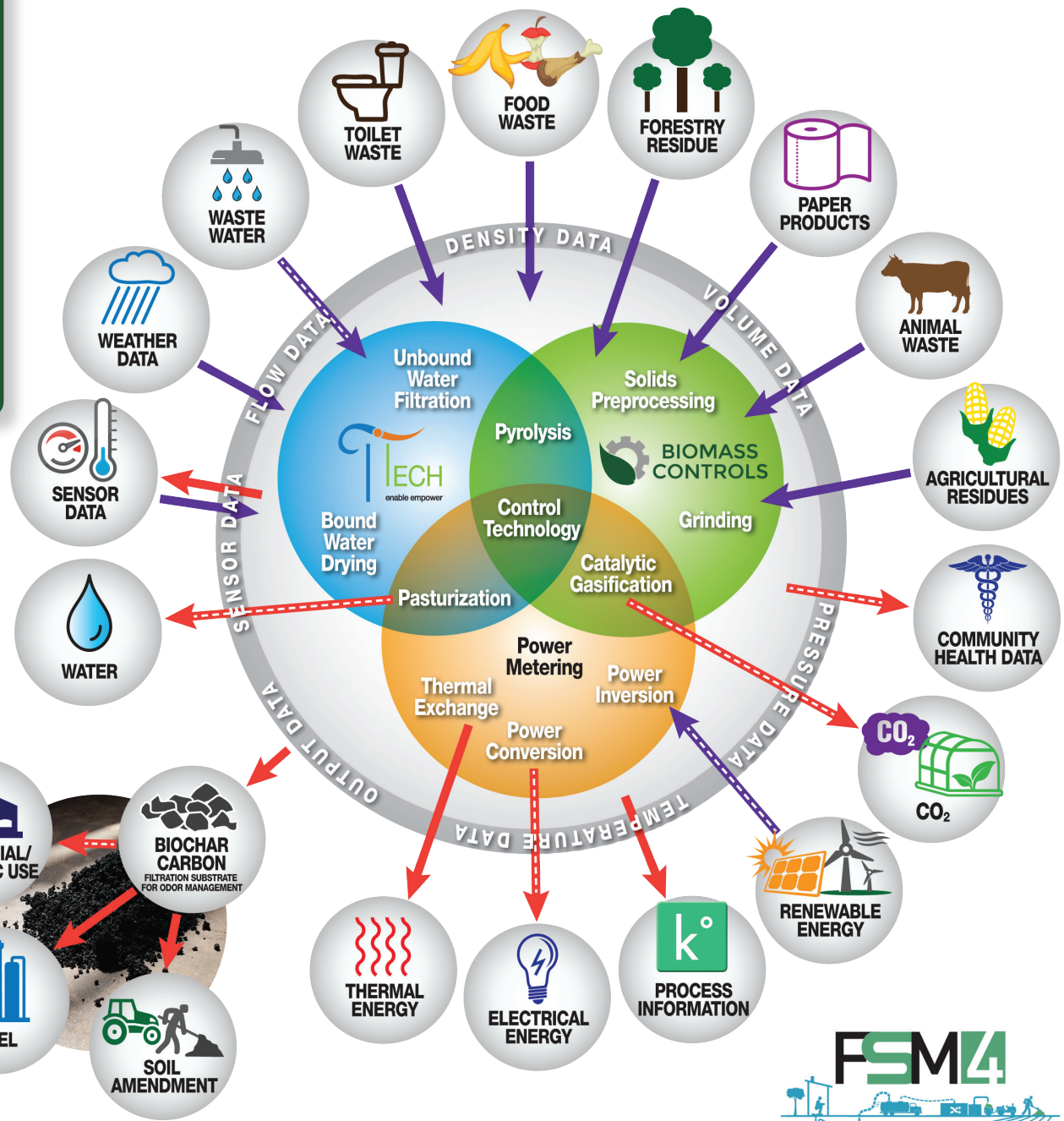
- ▶ Important to have variable controls
- ▶ The “one energy balance fits all” will not work



| Container Temperatures | | Kivalina System | | | |
|------------------------|---------|----------------------------|---------------|------------|------|
| 78°F | 68°F | RUN | 200 Watts | | |
| Controls | Ambient | 01:40:45 | Power Usage | | |
| 1150°F | | | Prime | | |
| Pyrolysis Temperature | | | | | |
| 990°F | | 26 | 35 | 20 | |
| Catalyst Temperature | | Primary Air | Fuel Auger | Char Auger | |
| 212°F | | Network Connection: [SSID] | | | |
| Stack Temperature | | Data Transfer | | | |
| | | Flash Drive | Kelv'n Direct | | |
| 1800 | | Restart | Shutdown | Open door | Plot |
| Oxygen Content | | | | | |



Biogenic Waste Refinery



Next Steps

Energy,
enthalpy,
mass, and
mass carbon
balance

Product
Integration

Exploring
hybrid
power
options



BIOMASS
CONTROLS



WE WOULD LIKE TO THANK OUR FUNDERS

- ▶ Bill & Melinda Gates Foundation
- ▶ The Kivalina City and Tribal Councils
- ▶ NANA (a Regional Native Corporation)
- ▶ Teck Resources Limited



Contact Biomass Controls

Thank you for your time!

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**BIOMASS
CONTROLS**



Work Cited

1. Laird, D. A., Brown, R. C., Amonette, J. E., & Lehmann, J. (2009). Review of the pyrolysis platform for coproducing bio-oil and biochar. *Biofuels, Bioproducts and Biorefining*, 3(5), 547-562.
2. Liu, Xuan, et al. "Characterization of human manure-derived biochar and energy-balance analysis of slow pyrolysis process." *Waste Management* 34.9 (2014): 1619-1626.

