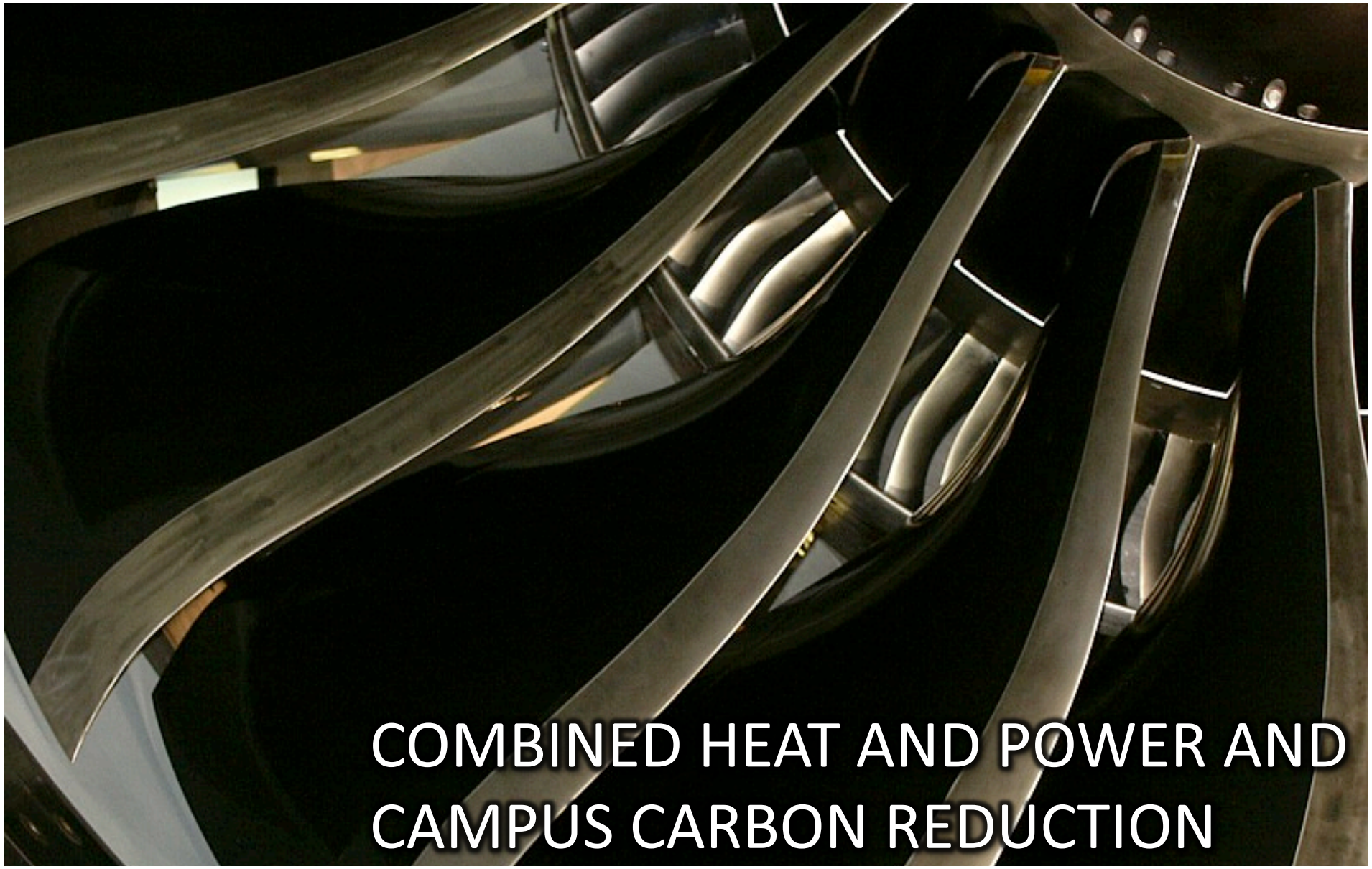


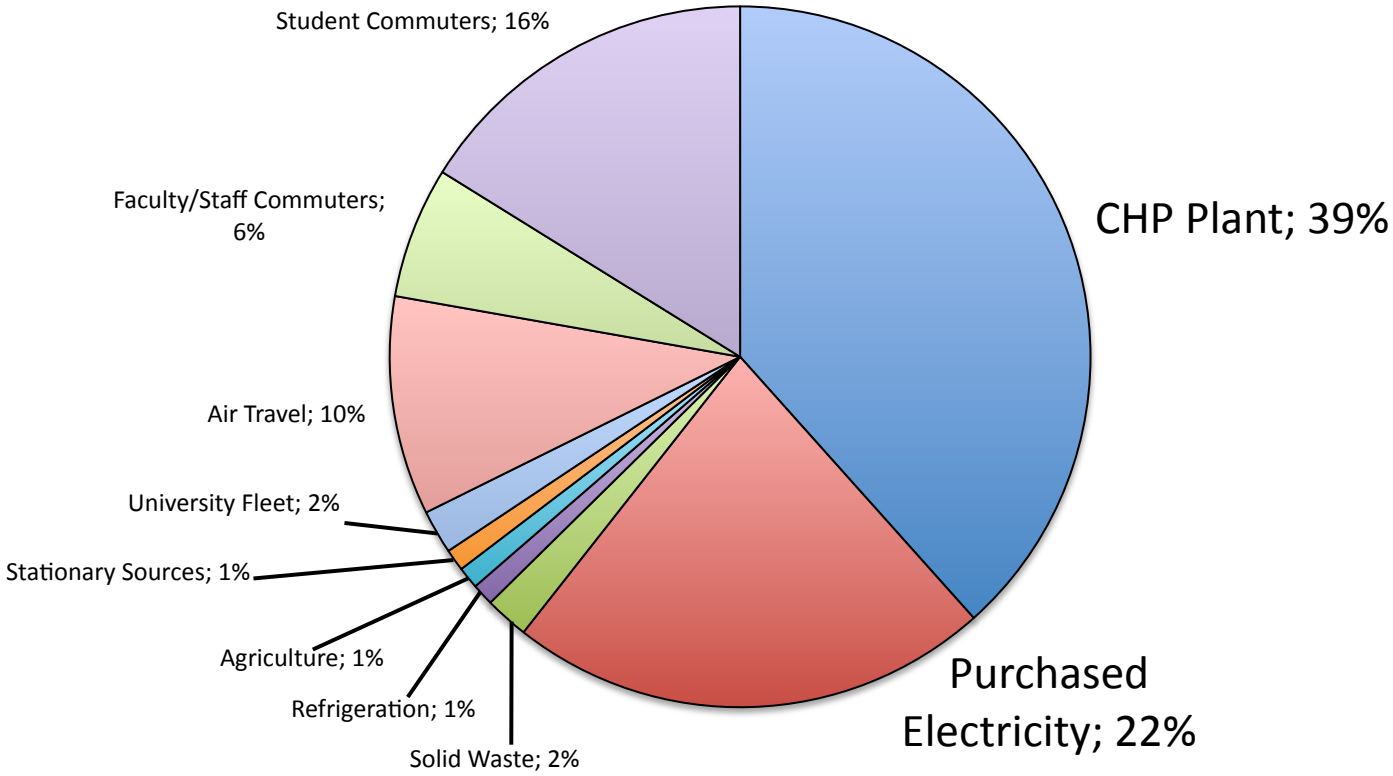
COMBINED HEAT AND POWER AND CAMPUS CARBON REDUCTION

Michelle Parks, Dylan Rebois, Jeff Tseng

Chris DeCaro, Christine He, Colin Kennedy, Ethan Schaler, Kenney Voshell

MOTIVATION

Sources of Campus GHG Emissions of a Select University



To what extent can university campuses reduce carbon dioxide emissions by effectively using CHP to meet electricity and thermal demands?

Technological Capacity

- Establish performance benchmark
- Investigate importance of turbine efficiency
- Evaluate cycle enhancements

Market Potential

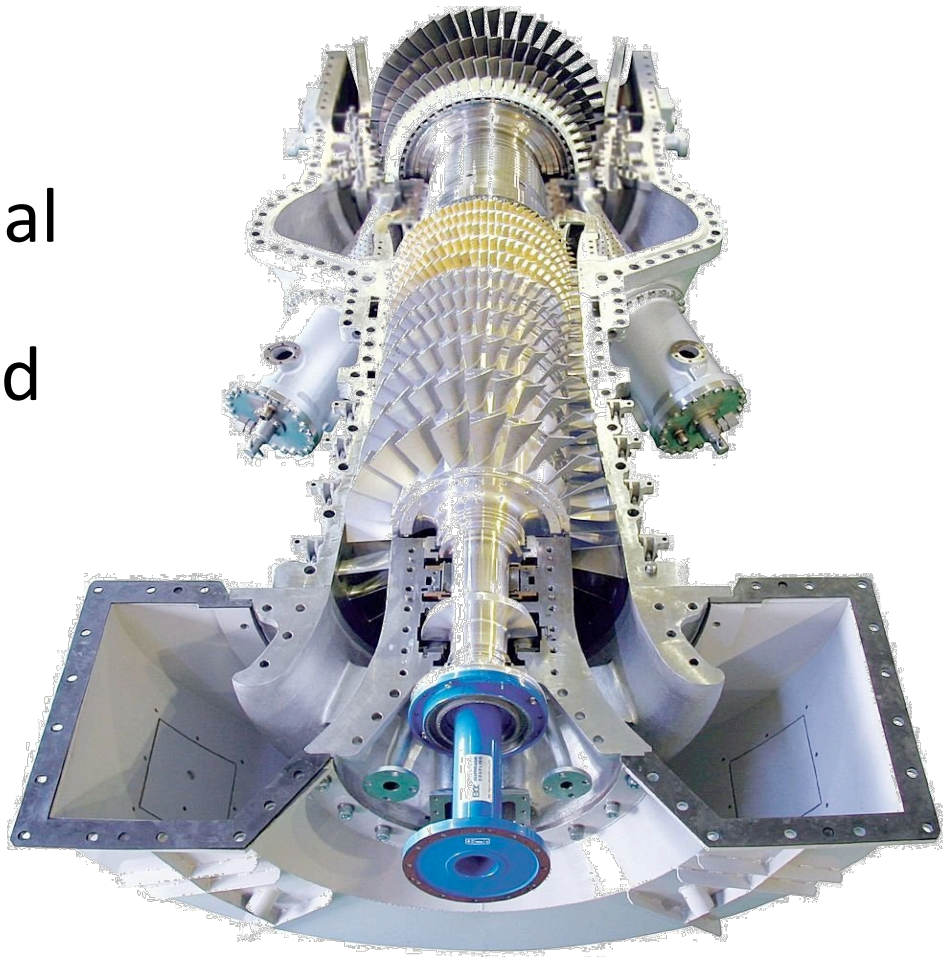
- Analyze existing market supply
- Develop a perspective on market demand
- Understand buyer perspective

Policy Barriers / Incentives

- Identify link between policy failings and emissions
- Describe objective-outcome gap
- Identify areas for policy improvement

PRESENTATION FOCUS

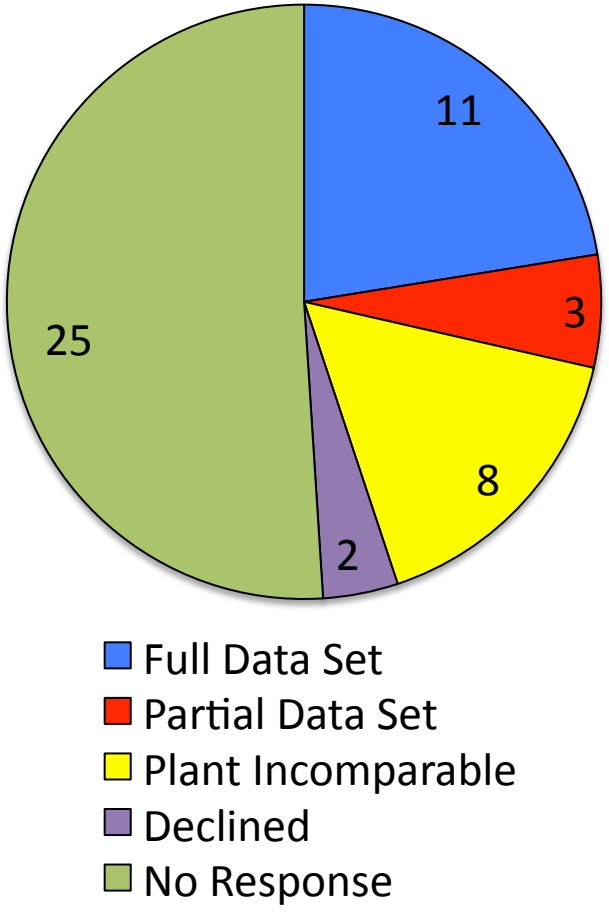
- Regional CHP potential
- Policy support needed
- University case study



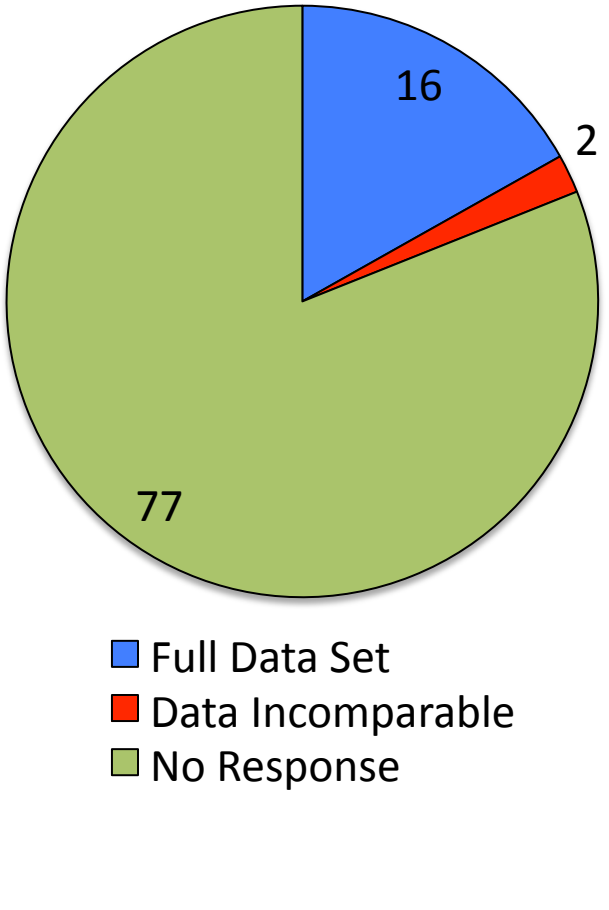
[2]

SURVEY RESPONSE CHARACTERISTICS

Efficiency Survey Response Characteristics



Market Survey Response Characteristics



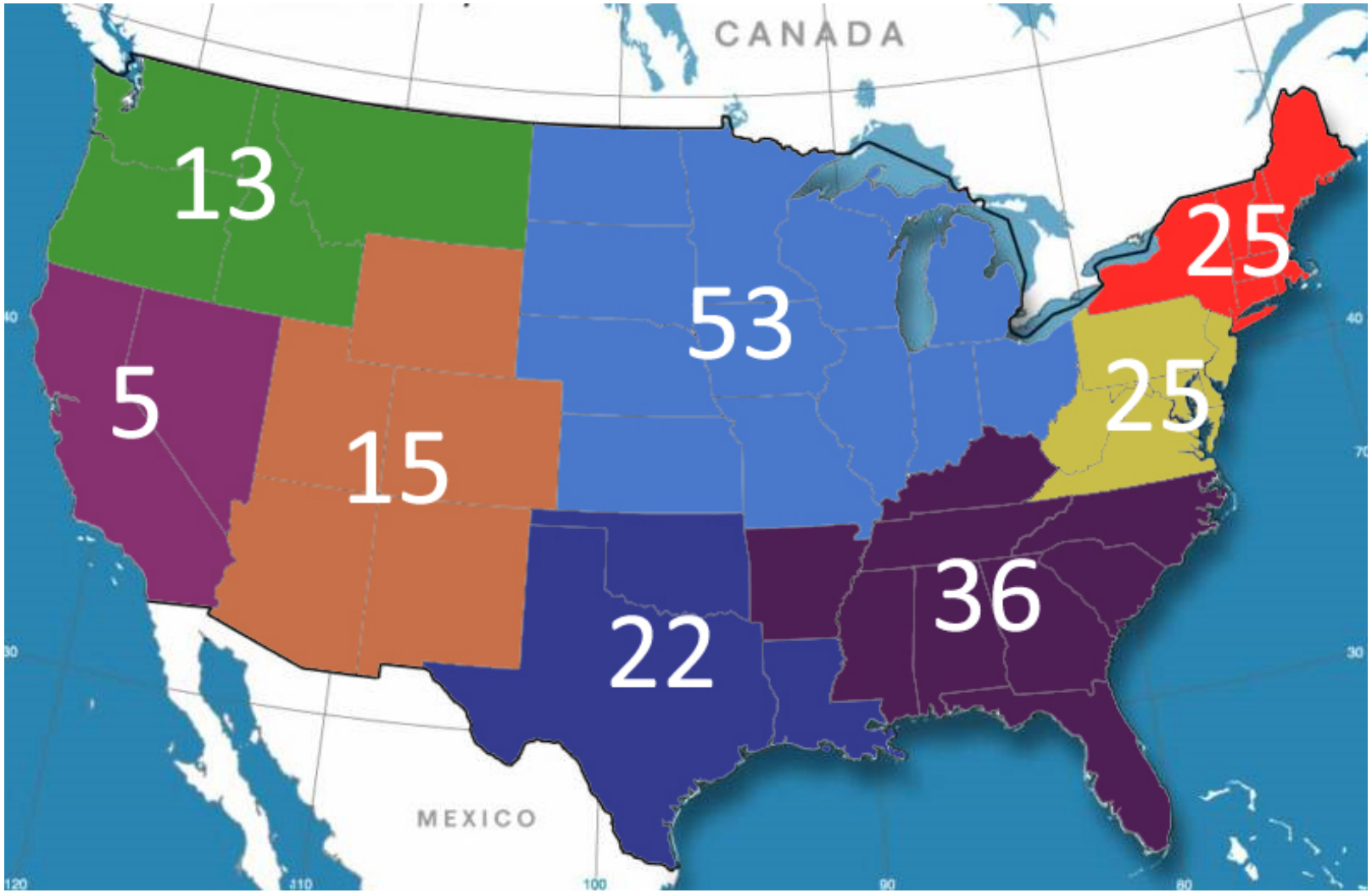
CHP POTENTIAL

Market study

- Lack of a high-efficiency, university-scale turbine
  - Efficiencies realized at higher capacities don't translate to smaller scales
  - Little perceived demand

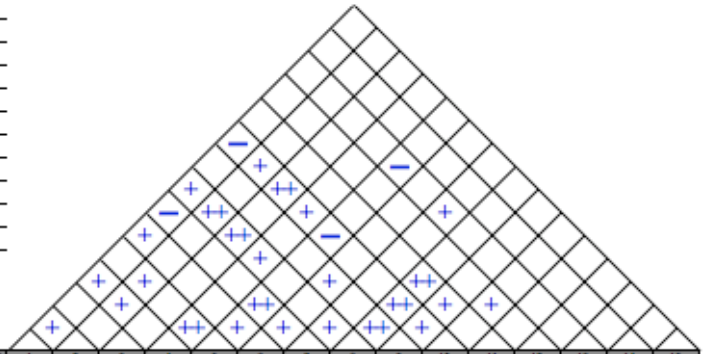
REGIONAL CHP POTENTIAL

Regional Technical Potential for Campus Energy Systems without CHP



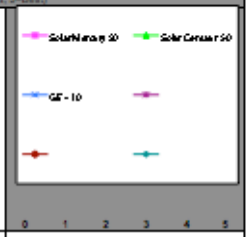
CHP POTENTIAL

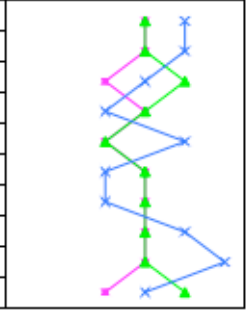
Title: Turbine Market House of Quality
Author: Team COGEN
Date: 2/14/11
Notes:



Legend		
⊖	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective is To Minimize	
▲	Objective is To Maximize	
X	Objective is To Hit Target	

Column #			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (1=Worst, 5=Best)					
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)			▲	▲	▲	▲	▲	X	▲	▲	X	▲	▲	▲	X									
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Compressor or Pressure Ratio	Aerodynamics (Blades/Stators)	Bearing Quality	Blade Metallurgy	Combustion Temperature	Turbine Generator Nominal Size	Recuperation	Manufacturing Quality	Gear Box Design	MTBF	Generator Efficiency	Air Filtering	HRSG Ductburner			Solar Mercury 50	Solar Centaur 50	GE - 10			
1	9	17.4	7.3	Reliability			⊖	⊖				⊖				⊖				3	3	4			
2	9	15.1	6.3	Alignment to Steam Demand													⊖			3	3	4			
3	9	14.1	5.9	Fuel Efficiency	⊖	⊖	O	⊖	⊖		⊖		⊖		⊖					2	4	3			
4	9	12.2	5.1	Price	⊖			⊖	⊖	⊖		⊖					⊖			3	3	2			
5	9	10.8	4.5	Alignment to Electricity Demand						⊖										2	2	4			
6	9	10.5	4.4	Maintenance										⊖						3	3	2			
7	9	8.9	3.7	Service/Support										⊖						3	3	2			
8	9	6.7	2.8	Longevity			⊖					⊖				⊖				3	3	4			
9	9	3.1	1.3	Product Reputation										⊖						3	3	5			
10	9	1.2	0.5	Physical Size						⊖										2	4	3			
				Target or Limit Value																					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																					
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9								
				Weight / Importance	237.0	127.1	259.3	393.8	237.0	217.8	127.1	326.8	127.1	202.8	127.1	216.9	245.7								
				Relative Weight	8.3	4.5	9.1	13.8	8.3	7.6	4.5	11.5	4.5	7.1	4.5	7.6	8.6								



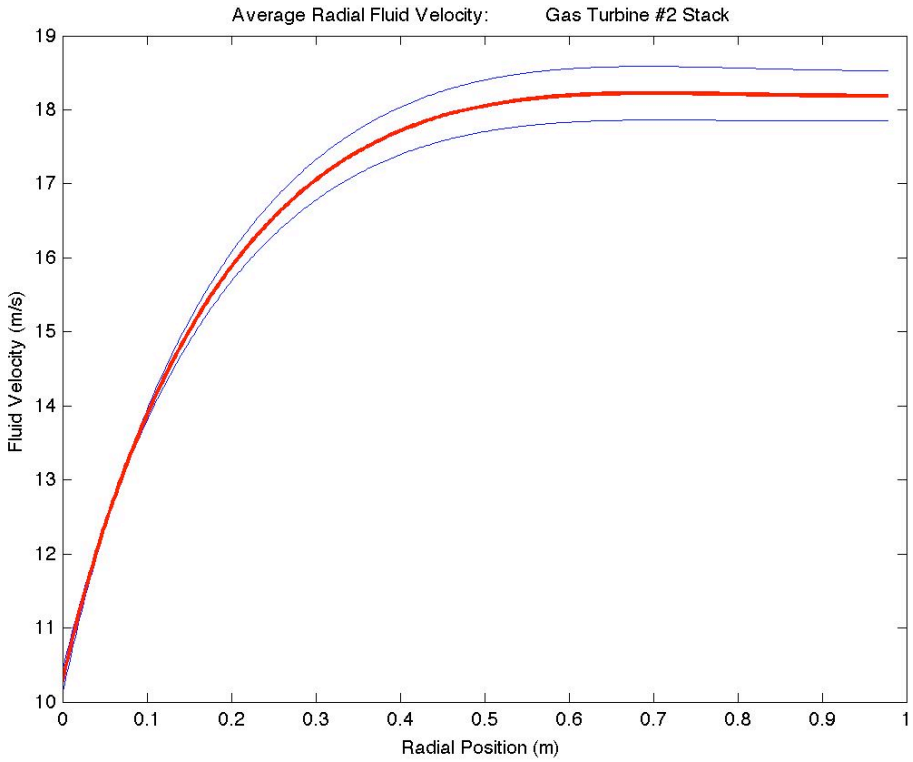


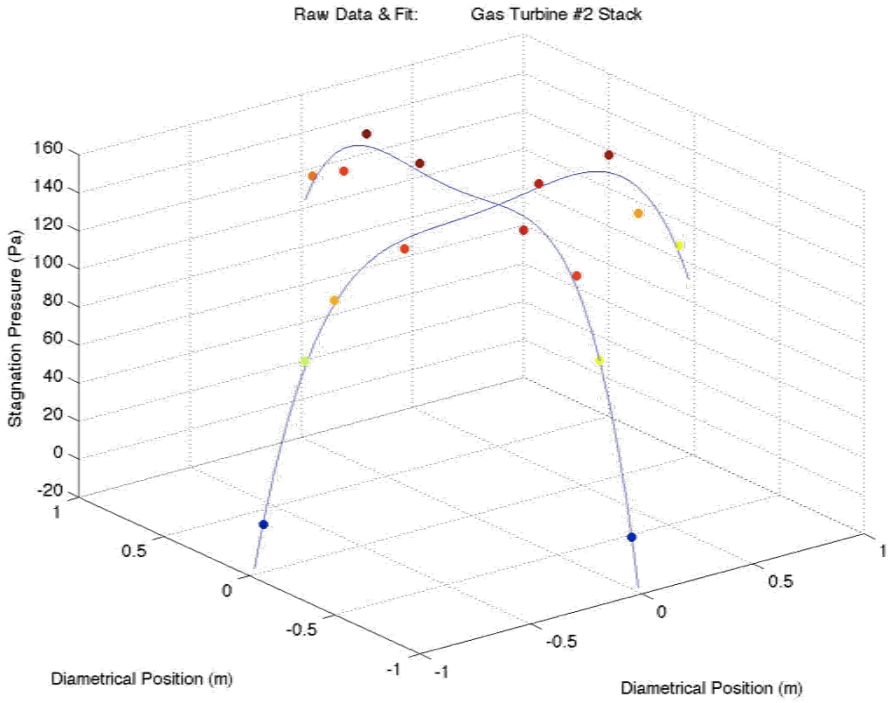
	Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	▲	▲	▲	x	▲	▲	x	▲	▲	▲	x		
Weight / Importance	**Demanded Quality** (a.k.a. "Customer Requirements" or "Whats") / **Quality Characteristics** (a.k.a. "Functional Requirements" or "Hows")	Compressor or Pressure Ratio	Aerodynamics (Blades/Stators)	Bearing Quality	Blade Metallurgy	Combustion Temperature	Turbine Generator Nominal Size	Recuperation	Manufacturing Quality	Gear Box Design	MTBF	Generator Efficiency	Air Filtering	HRSG Ductburner		
7.3	Reliability			Θ	Θ				Θ				Θ			
6.3	Alignment to Steam Demand													Θ		
5.9	Fuel Efficiency	Θ	Θ	O	Θ	Θ		Θ		Θ		Θ				
5.1	Price	Θ			Θ	Θ	Θ		Θ					Θ		
4.5	Alignment to Electricity Demand						Θ									
4.4	Maintenance										Θ					
3.7	Service/Support										Θ					
2.8	Longevity			Θ					Θ				Θ			
1.3	Product Reputation										Θ					
0.5	Physical Size						Θ									

Market study

- Demand for high-efficiency turbines exists, but not articulated
- Individual universities wield diminished buying power
  - Disparate priorities

Reconciling field data and thermodynamics

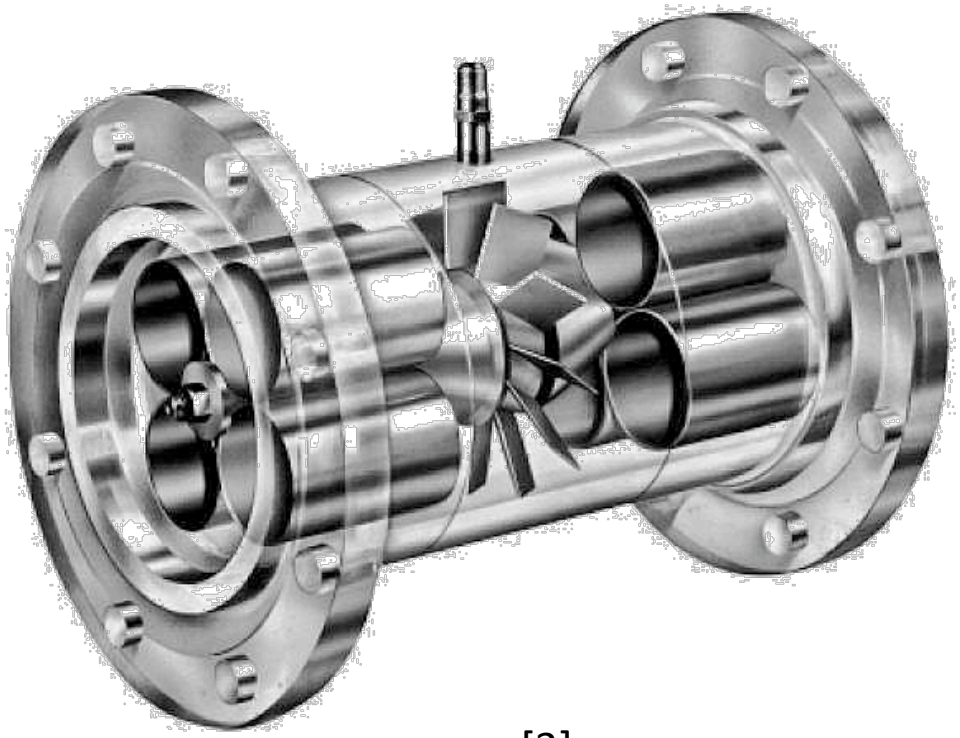




UNIVERSITY CASE STUDY

Benchmarking obstacles

- Irreconcilable field data
- Seasonal variation
- Plant performance monitoring



[3]

A sketch: carbon reduction potential from turbine improvement

$$\dot{m}_{fuel} = 0.6575 \text{ kg/s}$$

$$\dot{W}_{out-turbine} = 8.51 \text{ MW}$$

$$\dot{m}_{steam} = 5.985 \text{ kg/s}$$

$$\eta_{turbine} = 0.3500$$

$$\eta_{HRSG} = 0.685$$

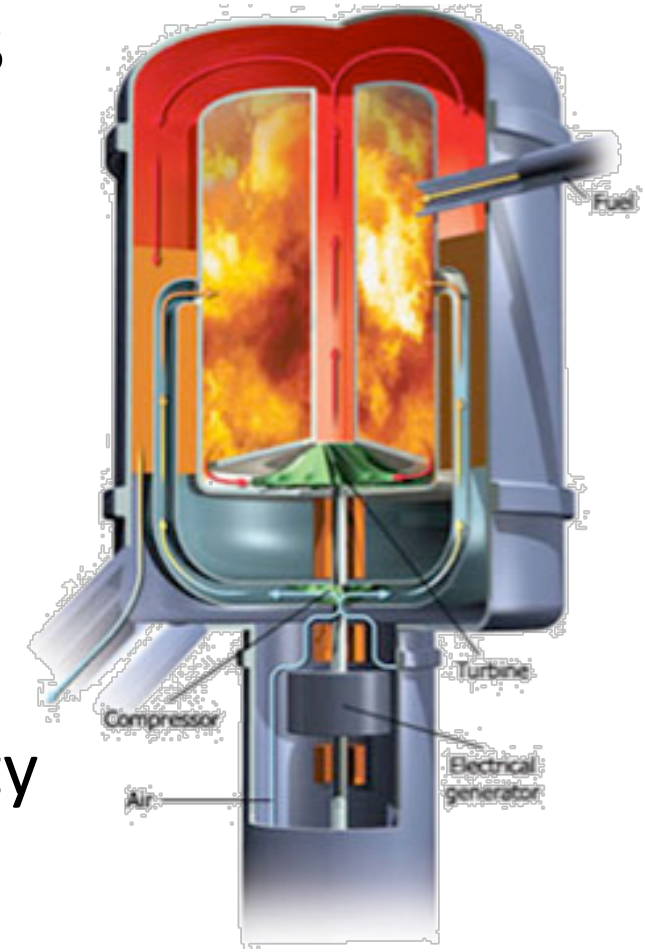
$$\eta_{system} = 0.8550$$

27,000 t CO_2

UNIVERSITY CASE STUDY

Turbine operation difficulties

- Combustor problem
  - Emissions implications
  - Purchasing lesson
- Low combustion temperature
  - Operators prioritize reliability over efficiency



[4]

Policy obstacles result in increased CO_2 emissions

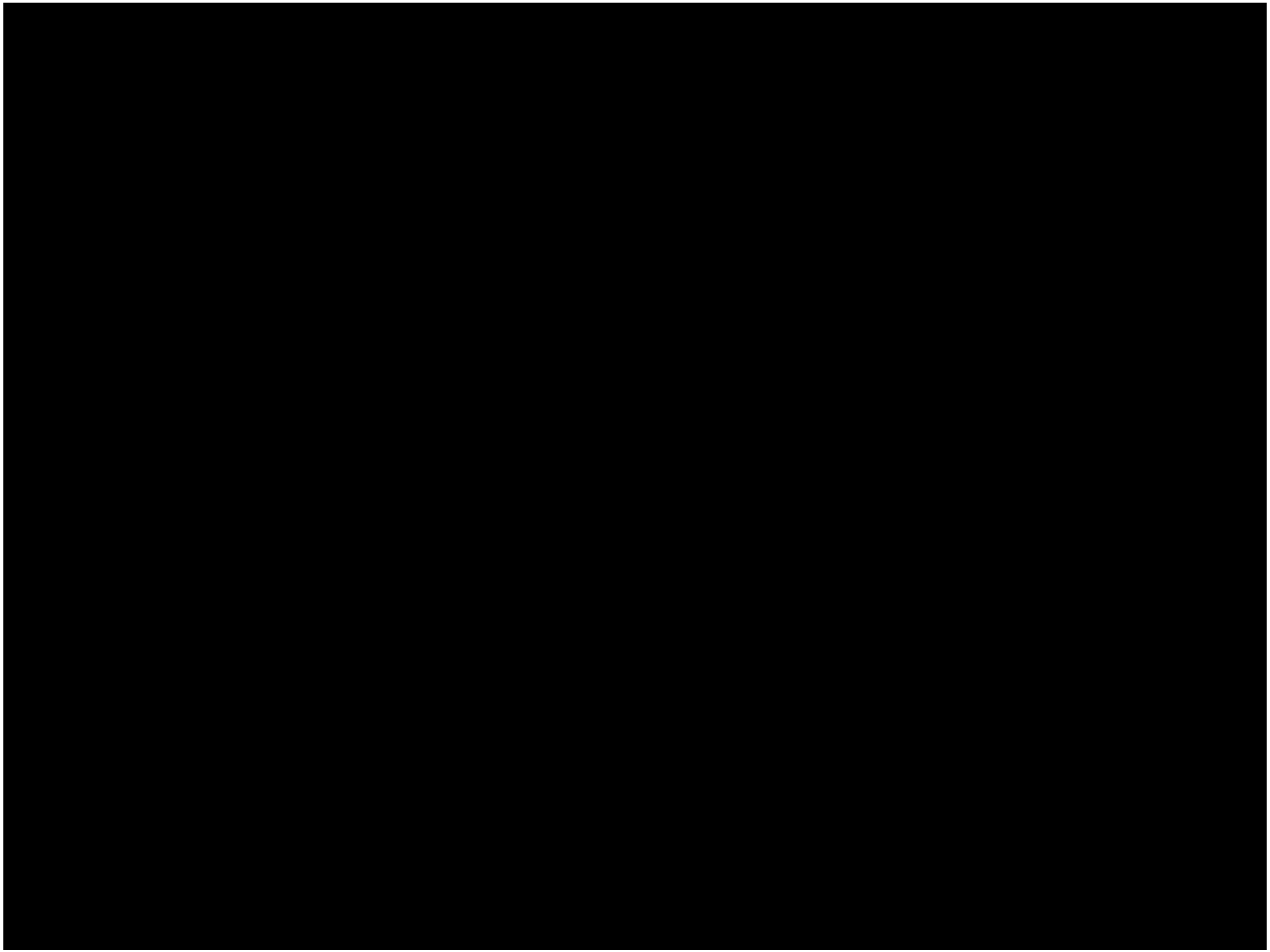
- Utility negotiations/interconnect agreements
- Operational contract decreases efficiency
- Exclusion from renewable incentives
  - RECs

SUMMARY AND DISCUSSION

- Large turbine performance in small turbines
- Demand for high efficiency turbines exists but not articulated in discourse
- Cost is an obstacle to better turbine development
- Obstacles to efficiency benchmarking represent obstacles to operational improvement

RECOMMENDATIONS

- Five-part consortium
  - University energy officials
  - Gas turbine manufacturers
  - Department of Energy
  - CHP Regional Application Center Directors
  - Utilities



REFERENCES

1. University of Maryland Climate Action Plan Workgroup. “University of Maryland Climate Action Plan.” Internet: http://acupcc.aashe.org/site_media/uploads/cap/278-cap.pdf, Aug., 2009 [Jan. 31, 2010].
2. "Jet Engine." Internet: http://onlineaircraftengineering.blogspot.com, 2010. [Feb. 20, 2011].
3. "Turbine Flow Meter." Internet: http://img.directindustry.com/images_di/photo-g/precision-gas-turbine-flow-meter-239362.jpg. [2009].
4. “Microturbines.” Internet: http://www.wbdg.org/images/microturbines_2.jpg. [2011].