INTEGRATED APPROACH TO BUILDING A MICROGRID

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AGENDA: concept to commissioning

- Introduction
- Microgrids – what, how and why?
- Sustainability (*reducing CO2 emissions*) <u>must</u> be Profitable (*increase ca$hflow)*
- "First Principles" of Microgrid development
  - Rapid concept creation
  - Economics: CapEx, OpEx + Risks & Mitigants
  - Contract structures & counterparties
    - Public Procurement
    - Private Procurement
  - Project Delivery & Commissioning
  - Operation & Maintenance (O&M)

Who is Energy & Water Development LLC?

Customized Energy and Water Development services; also known as **EnWaDev**.

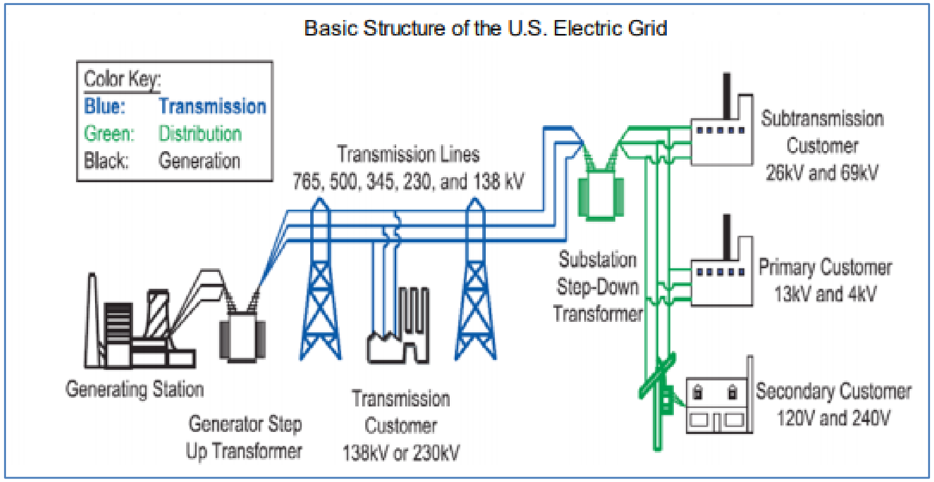
A. Consulting:
Energy & Water optimization strategy ("Demand Reduction", then "Supply Optimization") Investment grade financial analysis encompassing concept development, project structuring, contracting strategy, technology assessments, bid management, environmental impact, project schedule and constructability etc…

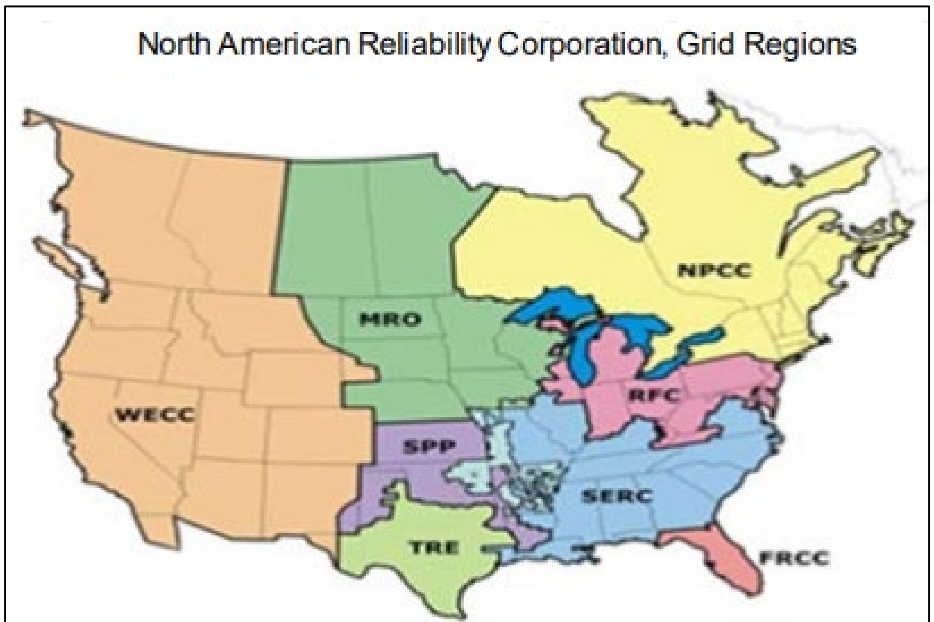
B. Development:
Design-Build and Own projects. Deliver as full-wrap Engineering Procurement & Construction (EPC) or part-wrap Engineering, Procurement & Construction Management (EPCM).

C. Operations & Maintenance:
Reliable energy & water to the customer and maintain asset value for the owner

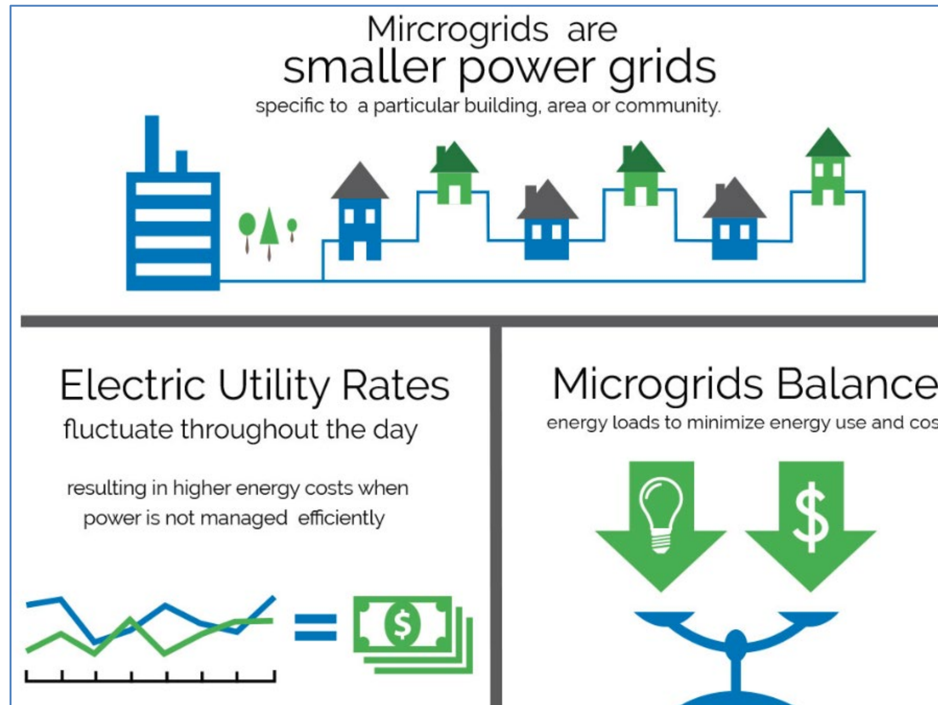
Assertions:
1. Efficiency *hedges* energy & water price volatility.
2. *Profitably* reduce Greenhouse Gas Emissions.
3. *No conflict* between your wallet and your conscience.

Regular Grid Vs. Microgrids





Microgrid: A set of interconnected loads and Distributed Energy Resources (DER) within defined electrical boundaries; this entity can connect or disconnect from the larger electrical grid to operate in grid-connected or in island mode.



Courtesy: Martin Energy Group, North America Reliability Corporation, US Canada Task Force

Microgrids: “old is new”

An existing concept updated by technological advances and market conditions.

Fuel Cell

Combined Heat and Power (CHP) Source

Renewable

1880s — *1970s Oil crisis* — *1990s* — *2???*

Local small generation plants, manually operated, using local energy resources.

POWER SYSTEMS CENTRALIZATION

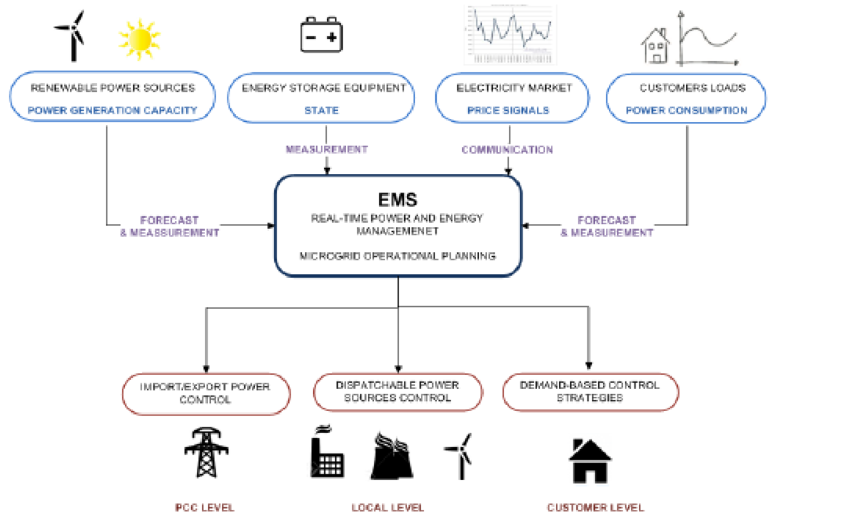
Big power plants and long transmission lines remotely operated.

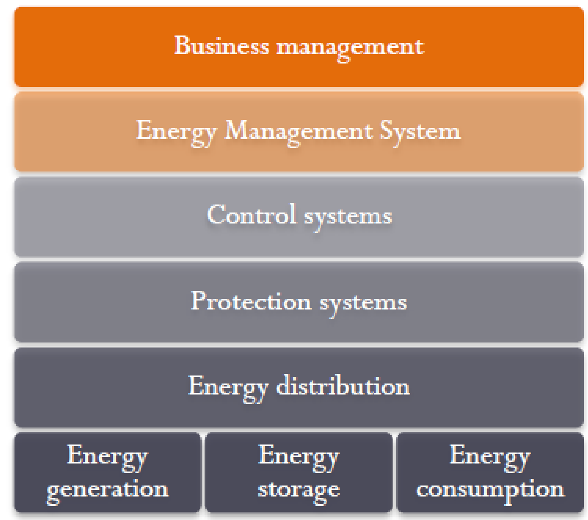
POWER SYSTEMS DECENTRALIZATION

1882 Microgrid: 150 KW coal-to-steam CHP system in Pearl Street, Manhattan, NY

2019 Microgrids: KW to 100+ MW systems configured around wind/sun/fuel cell + battery storage + CHP technologies (steam turbine, gas turbine, reciprocating engine)

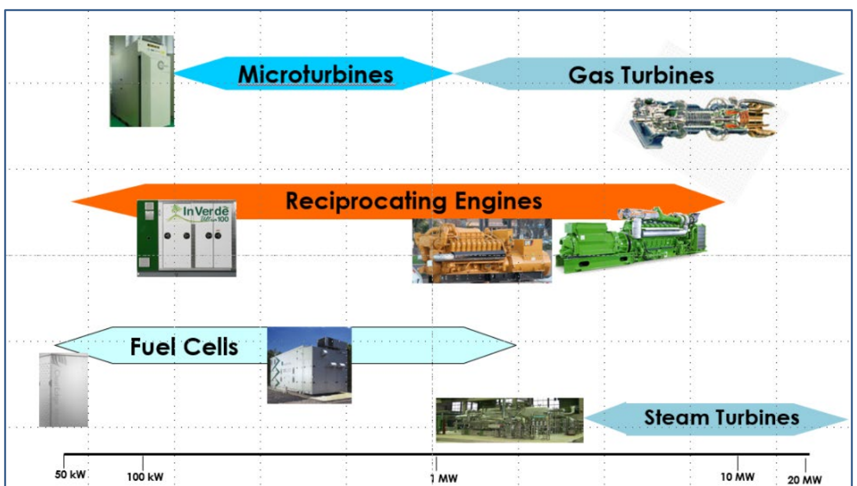
Microgrids: Components & Systems

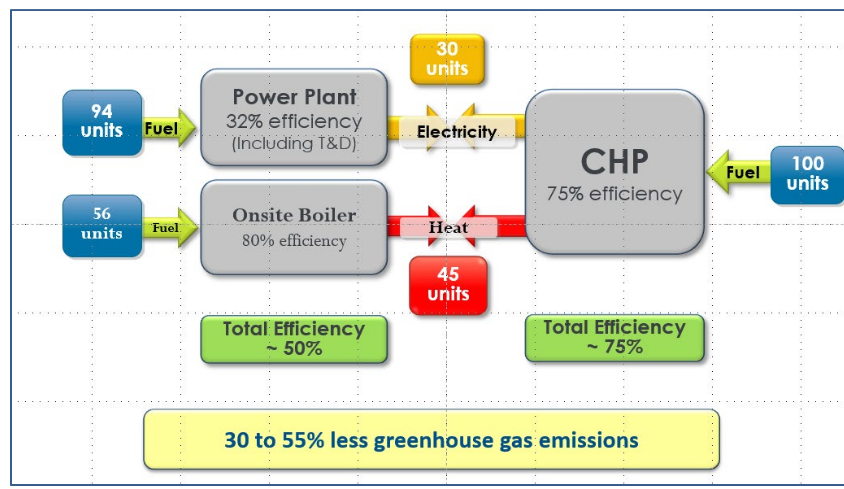




SOURCE: A KNOWLEDGE DISCOVERY IN DATABASES APPROACH FOR INDUSTRIAL MICROGRID PLANNING. Gamarra, C., Guerrero, J M., Montero, E. Renewable & Sustainable Energy Reviews. 2016. (doi 10.1016/j.rser.2016.01.091)

Clean natural gas fueled generators in Combined Heat & Power (CHP) configurations can be a foundational component of a microgrid. Thermal energy = useful byproduct.





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Why CHP in a microgrid? Two-for-one

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“Topping cycle” Combined Heat & Power (CHP) at University of Massachusetts, Amherst, MA.
Efficiency >80%

Traditional central power generation.
Efficiency ~35%.... burning money up the stack

OK – that's nice, but relevance to me?

Questions *(more on this next few slides)*

A. Do I need or want a microgrid?

B. How do I build it?

C. How do I Operate & Maintain it?

Project Development = Common Sense + Diligence

1. Set objectives & gather data
2. Conceptualize alternate configurations: technical & economic appraisal
3. Project development

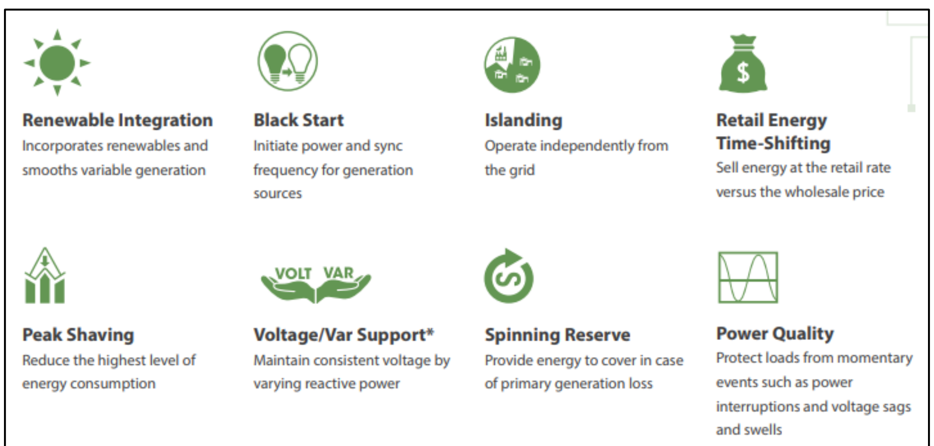
Technical:	Configuration, engineering, procurement, construction
Legal:	Structure of contracting entities (LLC, S or C Corp etc…)
Commercial:	Contracts for fuel, power, O&M, grants & incentives
Environmental:	Permits
Financial:	Financial models, equity & debt
Risks & Mitigants:	Project Execution Plan (PEP)

4. Operations & Maintenance (O&M)

A: Do I need or want a microgrid
Decision makers, considerations & benefits

CEO	Increase share holder value; augment business model
CFO	Increase site cashflow; several ways to finance the project
COO & Ops Staff	Maximize site uptime, increase resiliency
Grid Managers	Strengthen the grid, critical backup
Regulators	Protect the public by strengthen the grid / critical backup
Community	Sustainable - “be good and be green”

1. Consider the long-term viability of your site
2. Compare your alternatives
3. Quantify value streams



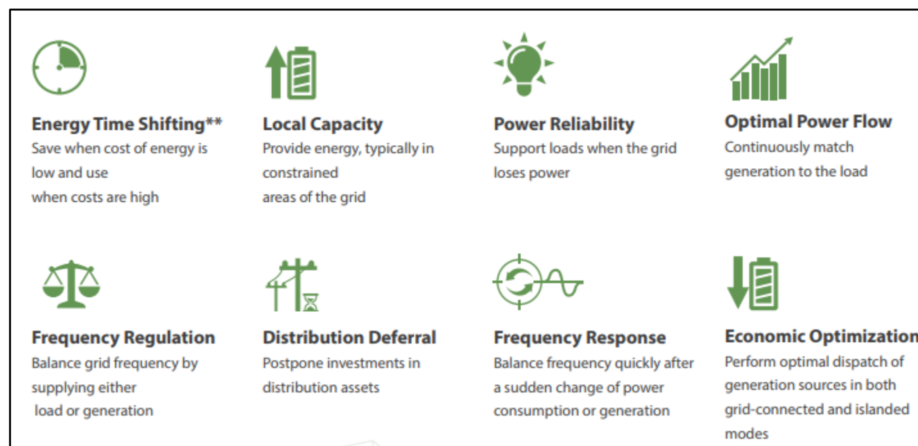


Image is courtesy S&C Electric

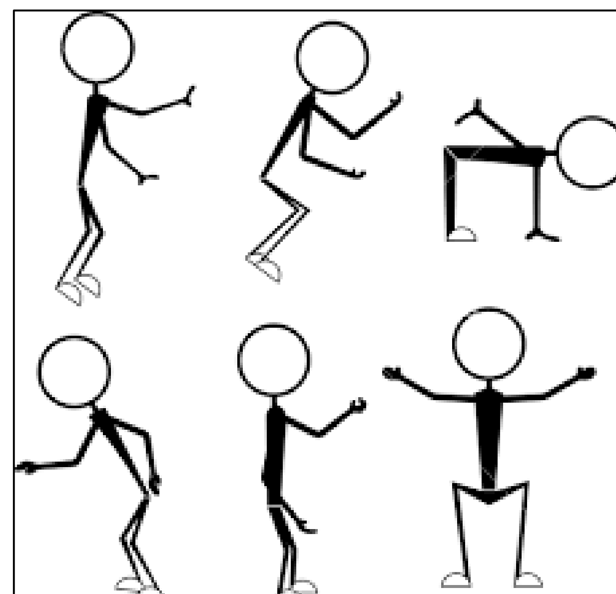
B: How do I build a microgrid? Thoughts & Actions

<u>Thoughts</u>

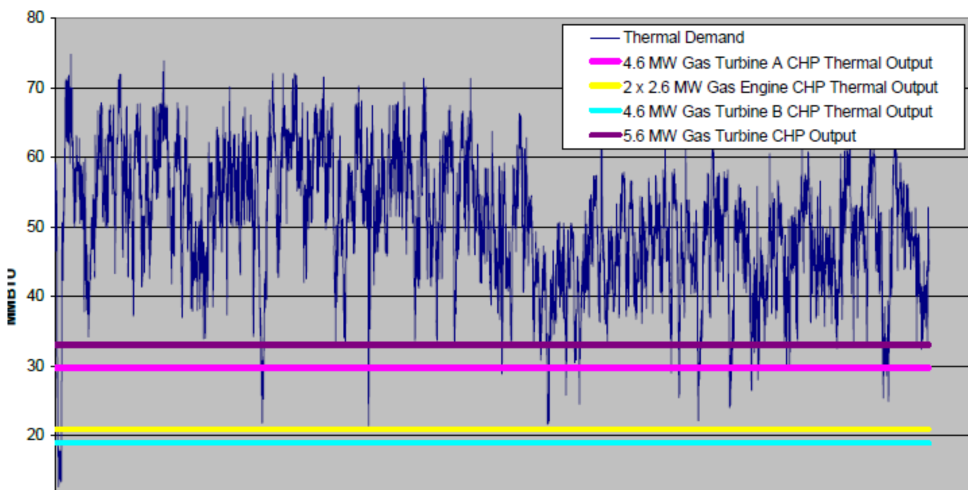
1. Safety & Security
2. Resiliency
3. Controllability
4. Investment & payback/NPV/IRR
5. Code Compliance
6. Sizing & Configuration
7. Off-Design Performance
8. Service Boundary
9. Schedule

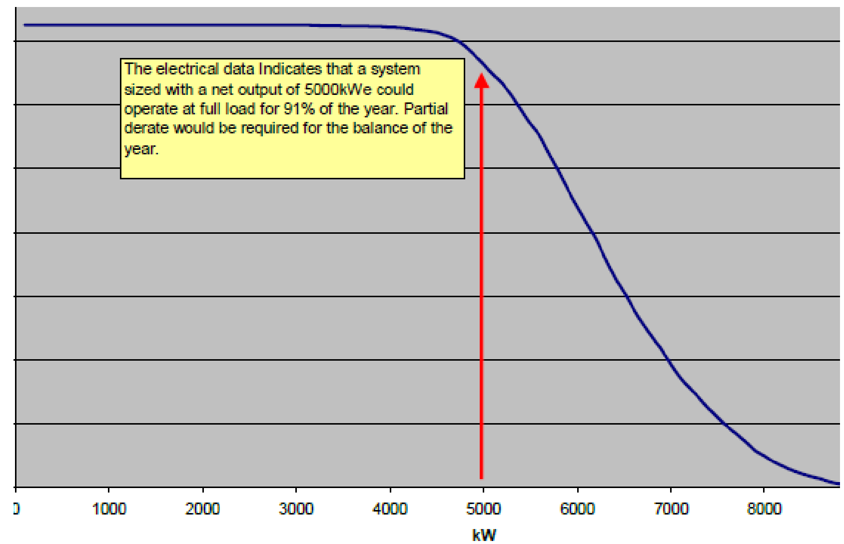
<u>Actions (*more in later slides*)</u>

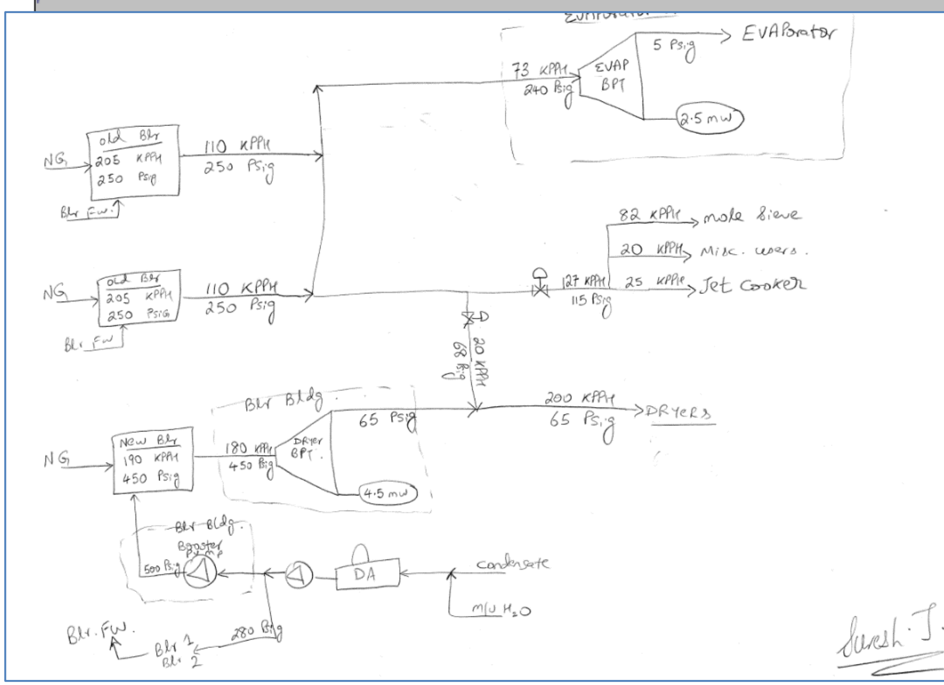
1. Screening
2. Feasibility study
3. Investment grade study
4. Engineering: Basic & Detailed
5. Procurement & Construction
6. Commissioning
7. Operations & Maintenance

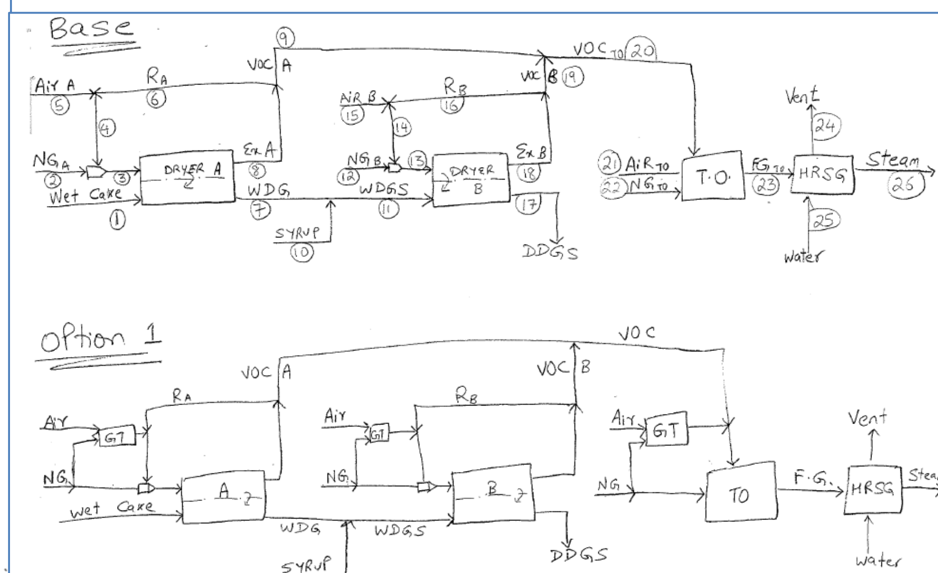


Start by graphing load profiles, then sketch ideas

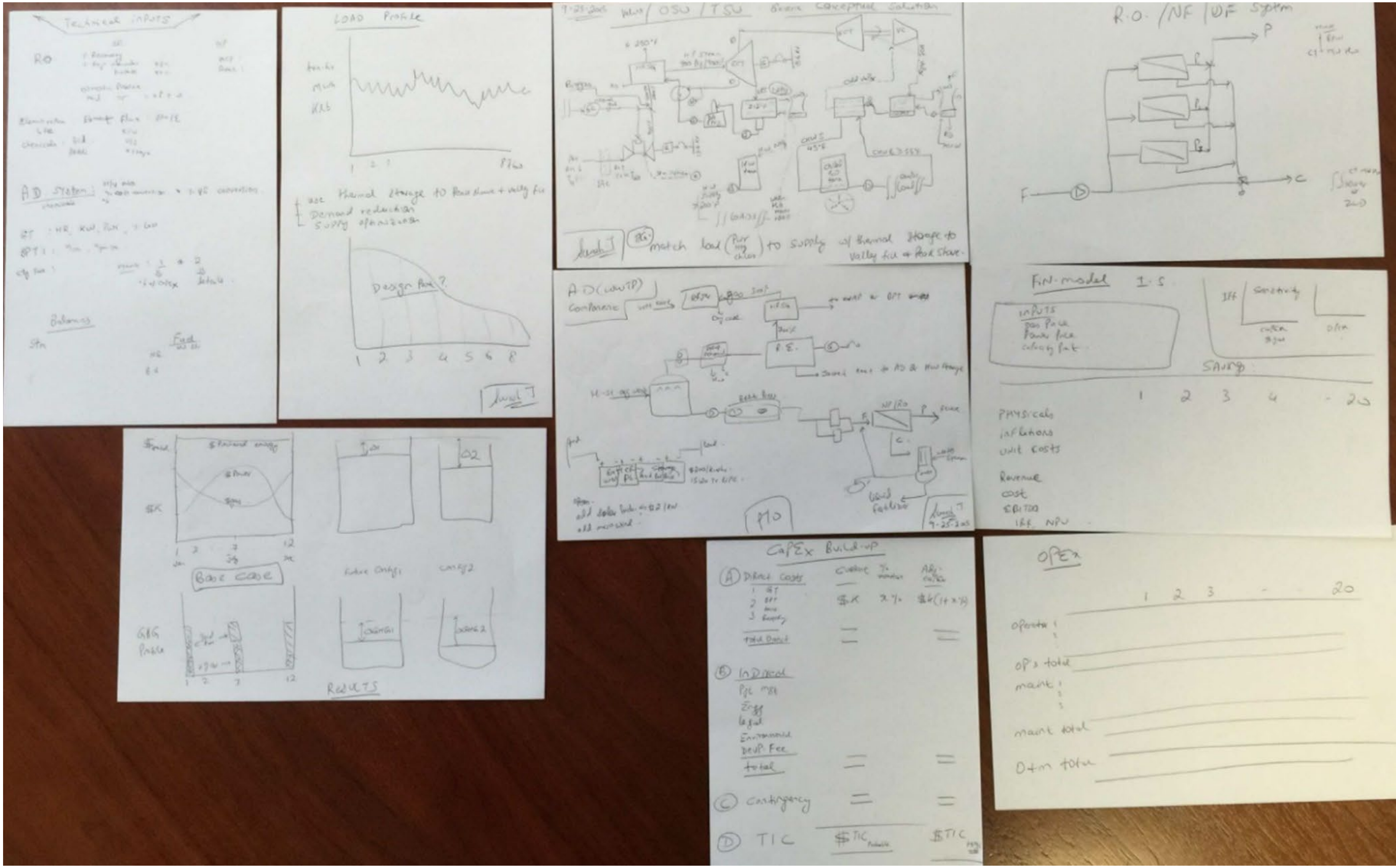




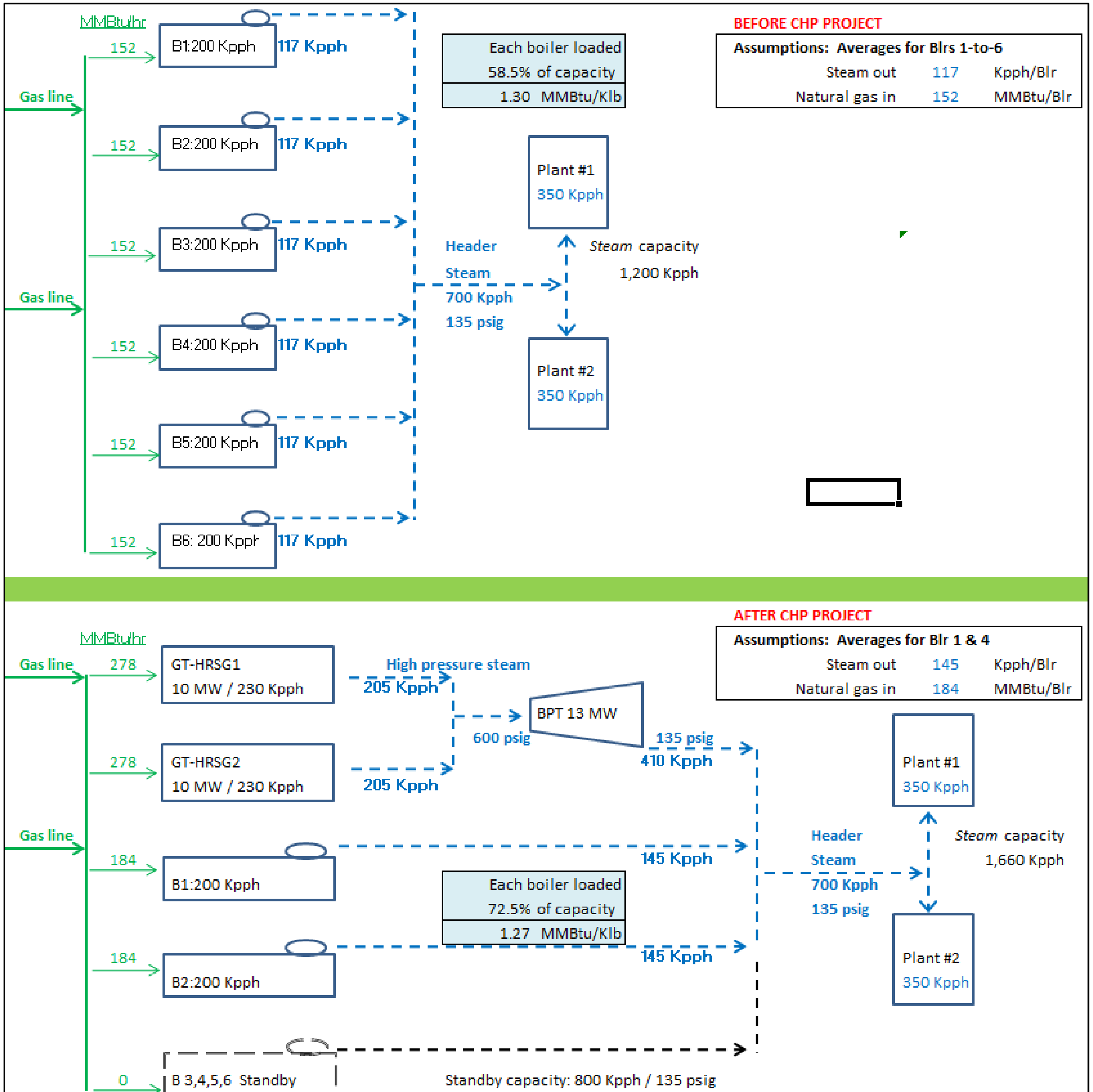




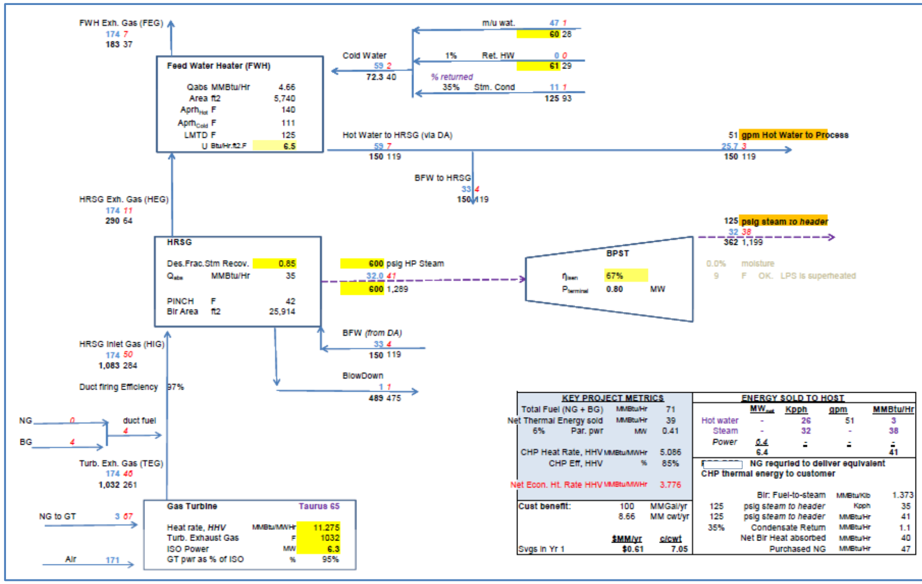
Pencil details – create configurations

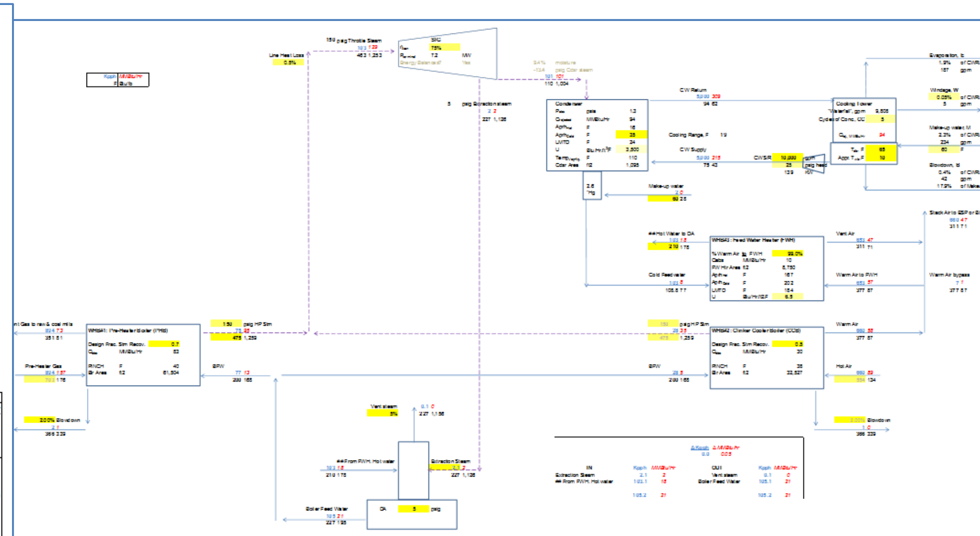


Baseline "before" case; consider "after" case



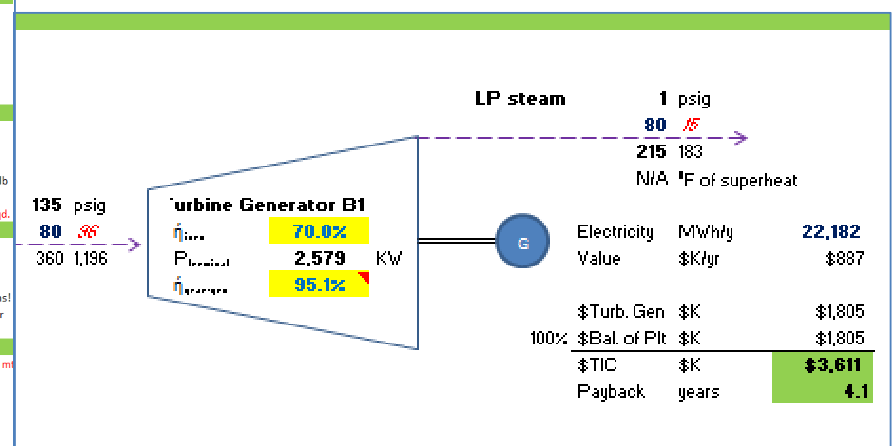
Mass & Energy Balance sizes & costs the project



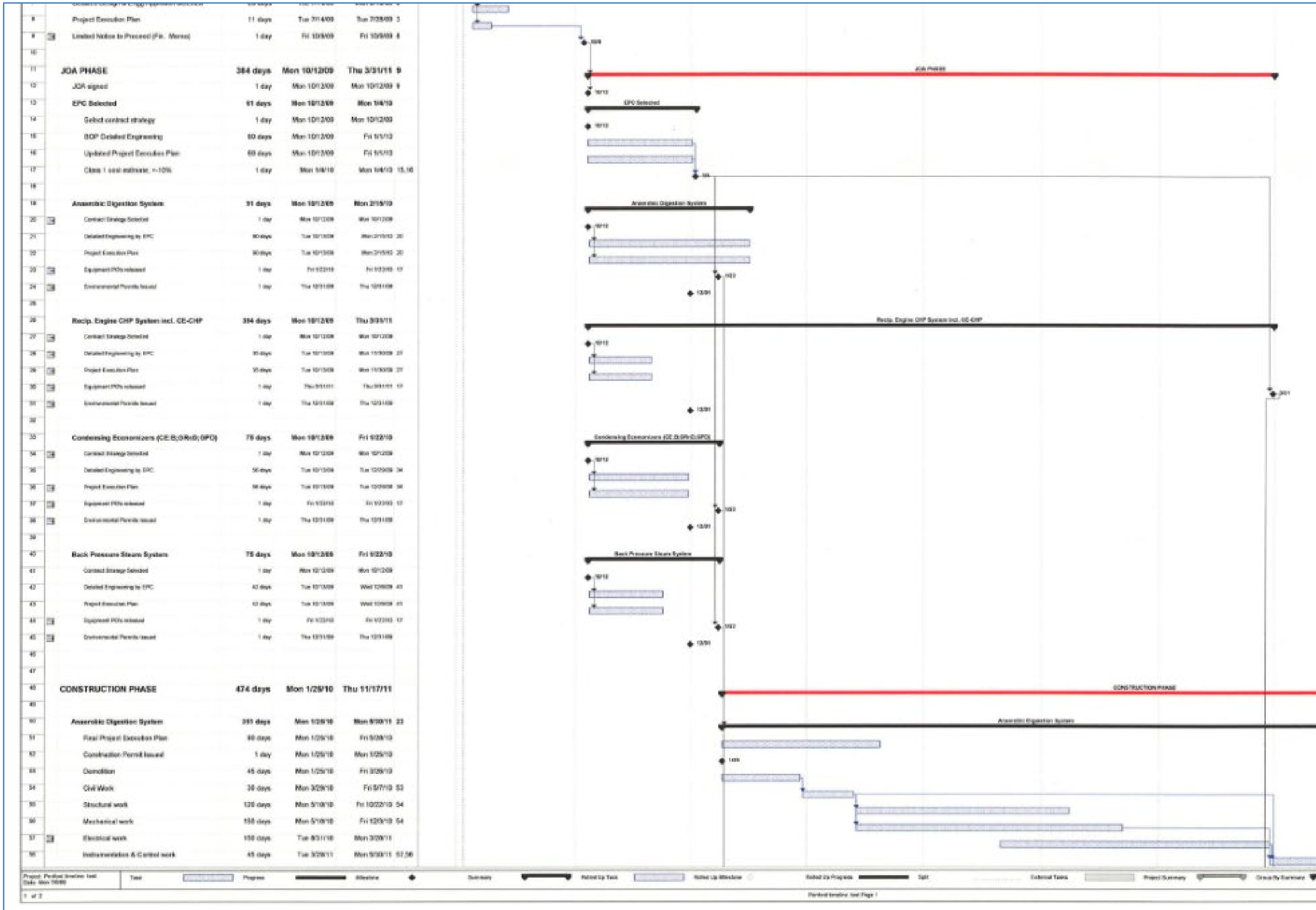


NOMINAL BALANCES: STEAM, FUEL, POWER and CO2 emissions

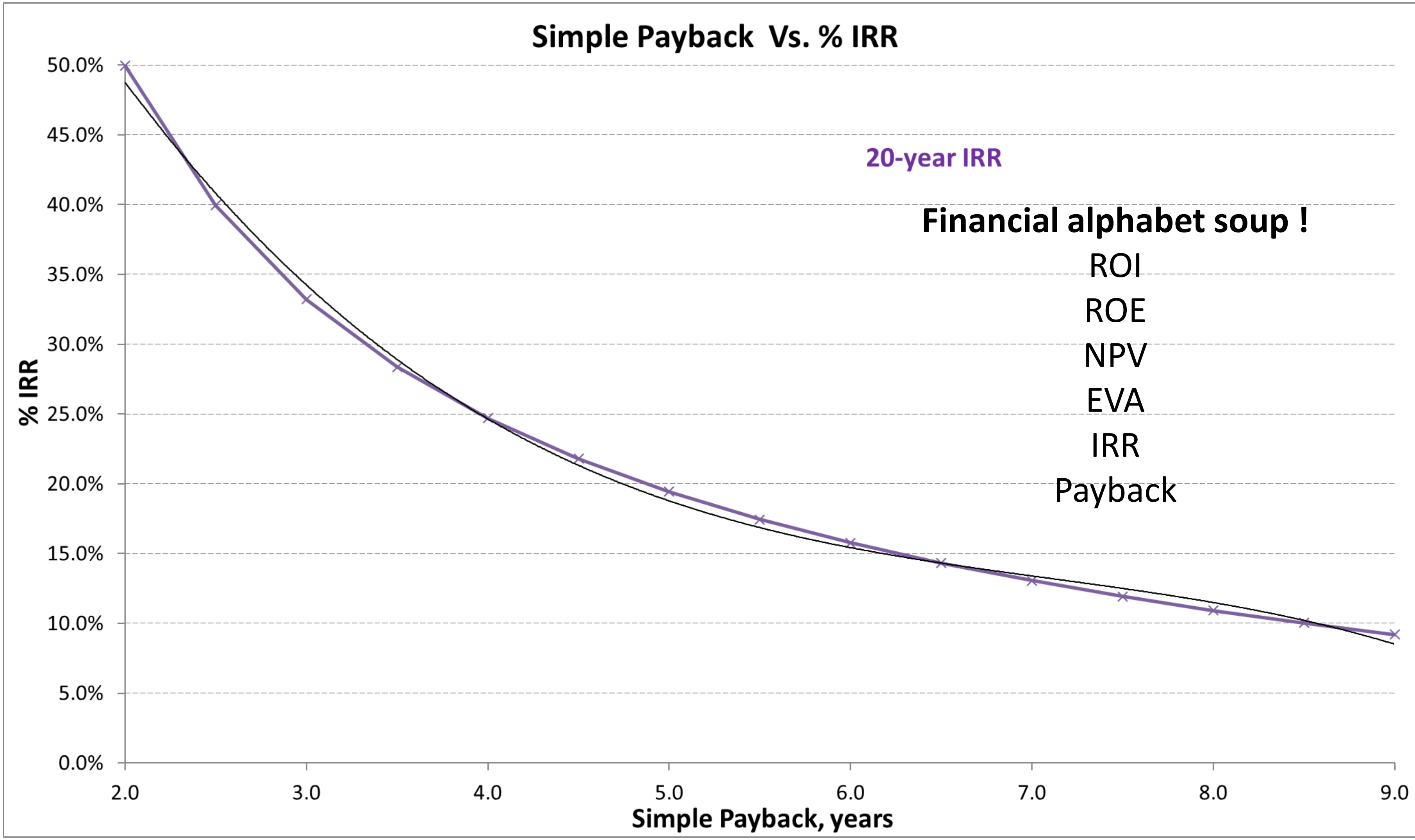
STEAM BALANCE									
BEFORE PROJECT	Kpph, each unit	Kpph, total	Klb/yr total	Comment	AFTER PROJECT	Kpph, each unit	Kpph, total	Klb/yr total	Comment
Boilers 1-to-6	117	700	6,048,000	Loaded 58.3%	Boilers 1 & 4 (2-optg blrs)	145	289	2,554,500	Loaded 72.3%
CHP (2x1 CC Config.)	0	0	0		CHP (2x1 CC Config.)	206	411	3,493,500	
TOTAL	-	700	6,048,000		TOTAL	-	700	6,048,000	
GAS BALANCE, LHV MMBtu									
BEFORE PROJECT	MMBtu/hr, each unit	MMBtu/hr total	MMBtu/yr total	Comment	AFTER PROJECT	MMBtu/hr, each unit	MMBtu/hr total	MMBtu/yr total	Comment
Boilers 1-to-6	152	910	7,862,400	Blrs = 1.3 MMBtu/Klb	Boilers 1 & 4 (2-optg blrs)	184	367	3,244,215	Blrs = 1.27 MMBtu/Klb
CHP (2x1 CC Config.)	0	0	0		CHP (2x1 CC Config.)	278	555	4,720,587	
TOTAL	152	910	7,862,400		TOTAL	461	922	7,964,802	1% change in gas reqd.
POWER BALANCE									
BEFORE PROJECT		MW_e	MWh/yr	Comment	AFTER PROJECT		MWe	MWh/yr	Comment
Host: Pwr from grid		22.5	194,400		Host: Pwr from grid		0.2	4,482	import a few electrons!
Host: Net Pwr from CHP		0.0	0		Host: Net Pwr from CHP		22.34	189,918	Fuel-free clean power
TOTAL		22.5	194,400		TOTAL		22.5	194,400	
CO2 EMISSIONS BALANCE, metric tonnes (mt)								GHG reduction	71,236 mt
BEFORE PROJECT	lb/gallon ethanol	mt/hr	mt/yr	Comment: CO2 from	AFTER PROJECT	lb/gallon ethanol	mt/hr	mt/yr	Comment: CO2 from
Gas to Blrs	1.2	19.0	164,383	Gas	Gas to Blrs	0.5	7.9	67,828	Gas
Gas to CHP	0.0	0.0	0	Gas	Gas to CHP	0.7	11.6	98,695	Gas
Grid purchased power	0.6	8.7	75,109	22.5 MW grid pwr	Grid purchased power	0.0	0.2	1,732	0.16 MW grid pwr
TOTAL	1.8	27.7	239,492		TOTAL	1.2	19.7	168,255	30% GHG emissions red



Good schedule = "Project Execution Plan (PEP)"
Critical path = improves financial projections



Financial metrics: Payback or IRR….. Other?



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Model financials to identify & mitigate risks

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RISK	BORNE BY	MITIGANT
CHP system CapEx	Project, LLC	Clearly define scope + maximally utilize existing assets
CHP system OpEx	Project, LLC	Maximally utilize existing assets & people
CHP system performance - MW & Kpph	Project, LLC	Define site energy demand profile, perform component & system failure analysis
CHP system availability (Optg hrs)	Project, LLC	Good housekeeping, pro-active maintenance program
CHP stand-by charge	Host, Project LLC	Work with utility; demonstrate grid support benefits of CHP
Gas Price change	Host	Design for minimal incremental gas exposure
Power price change	Host	Work with utility to aid their load growth plan ("IRP")
Site / mill risk	Host	Demonstrate site competitveness vis-à-vis regional competitors, Put
Site availability (Optg hrs)	Host	Demonstrate site competitveness vis-à-vis regional competitors, Put

FIGURES IN BLUE ARE INPUTS

INPUT	UNIT	VALUE	COMMENT
FINANCING STRUCTURE (BY DEVELOPER)			
Debt: Equity ratio	%	85%	Assumed Exim Bank
Debt: Interest Rate	%	5.5%	LIBOR + 2.0%
Debt term	years	10	Assumed
KEY ECONOMIC PARAMETERS			
WHP Installed CapEx	$MM	$8.0	Assumed
Value of ORC power	c/KWh	12.0	12-50 c/kwhr
ORC Heat to Power Efficiency	%	17.0%	typical
Ship Availability	Optg hrs/yr	6,840	assumed
Salvage value of asset	% of New	10%	assumed
Operations & Maintenance			
Fixed Maintenance / LTSA	% of CapEx	2.0%	assumed
Labor: # of FTEs		4	assumed
Labor: fully loaded unit cost	$/hr	$25	assumed
Labor: % utilization	%	5.0%	assumed
Technical: Main Engine Size	MW	50	
Engine Exhaust Gas (EEG) - Mass flow	lb/hr	812,981	367200 Kg/hr
Engine Exhaust Gas (EEG) -inlet to ORC	F	536	280 C
Engine Exhaust Gas (EEG) -exiting ORC	F	275	135 C
Engine Exhaust Gas (EEG) - sp. Ht, Cp	Btu/lbF	0.29	

OUTPUT	UNIT	VALUE	COMMENT
10-yr Pjt ROI	**%**	**24.8%**	**4.1 years payback**
10-yr Pjt ROE	%	107.2%	1 years Equity payba
Equity (by developer)	$MM	$1.2	
Debt amount financed	$MM	$6.8	
Total Financing	$MM	**$8.0**	
ORC Net Power	**MW_e**	**3.07**	estimated
WHP Installed CapEx	$MM/$MW_e$	$2.61	calculated
Fixed Maintenance / LTSA	$K	$160	
Labor	$K	$10	
O&M, Yr 1	**$K**	**$170**	
O&M, Yr 1	c/KWh	0.8	
Available Waste Heat in EEG	MMBtu/Hr	118.8	Baseline 32F/ 0C
WH recovered in ORC unit	**MMBtu/Hr**	**61.5**	
Unrecovered WH	MMBtu/Hr	57.3	

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ECONOMICS: For CapEx, avoid +/- estimates. Use Likely case Vs. Worst case approach

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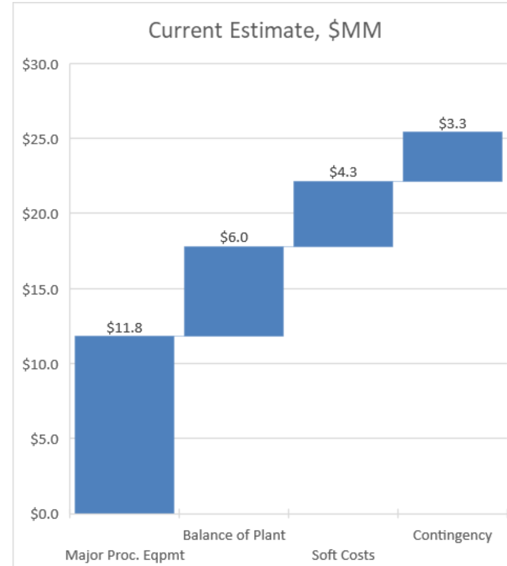
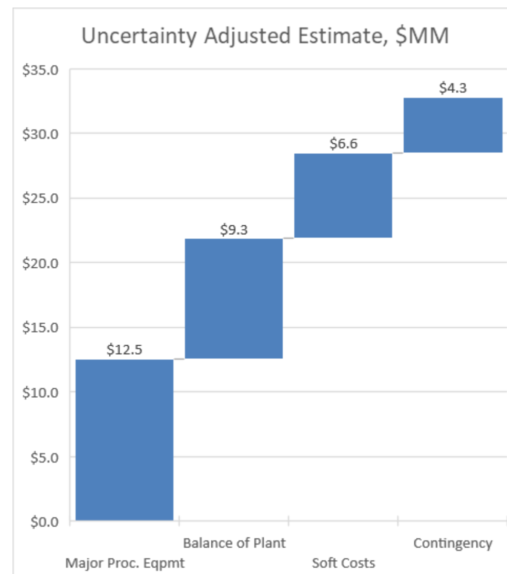
FIGURES IN BLUE ARE INPUTS   Stage:______________   Date:________

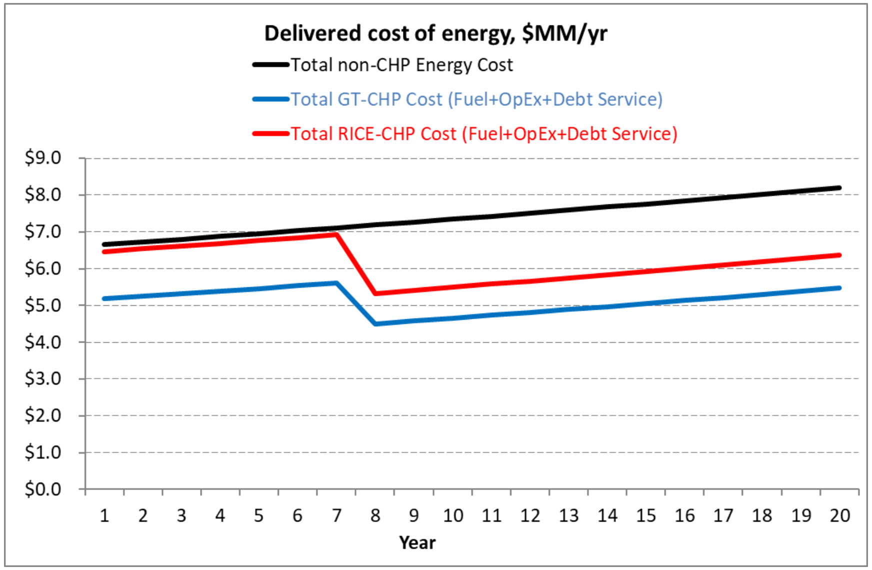
	CapEx: ___________ Configuration		Current Estimate	% Uncertainty	Uncertainty Adjusted Estimate	Comment
			$MM	%	$MM	
			$25.4	29%	$32.7	
A	Major Process Equipment ("Direct Costs")					
	Solar PV panels		$1.5	10%	$1.7	Vendor quote
	Battery Energy System		$4.5	5%	$4.7	Vendor quote
	CHP: Engine + Generator		$4.0	5%	$4.2	Vendor quote
	CHP: HRSG		$1.0	5%	$1.1	Vendor quote
	Other (switchgear, DA/pumps etc...)		$0.8	15%	$0.9	Factored Estimate
	Major Proc. Eqpmt		**$11.8**	**6%**	**$12.5**	
B	Balance of Plant, BOP ("Direct Costs")					
	Civil		$1.0	75%	$1.8	Est. (*Qty x unit cost*)
	Mechanical		$1.5	50%	$2.3	Est. (*Qty x unit cost*)
	Electrical		$2.0	40%	$2.8	Est. (*Qty x unit cost*)
	Instrumentation & Controls		$0.5	100%	$1.0	Est. (*Qty x unit cost*)
	Other		$1.0	50%	$1.5	SWAG !
	Balance of Plant		**$6.0**	**55%**	**$9.3**	
C	Soft Costs ("Indirect Costs")					
	Detail Engineering		$1.0	15%	$1.2	Fixed fee quote
	Project Management		$0.5	15%	$0.6	Fixed fee quote
	Construction Management		$0.5	15%	$0.6	Fixed fee quote
	Legal fees		$0.5	100%	$1.0	SWAG
	Financing charges		$0.5	40%	$0.7	Financier e-mail
	Environmental / permitting		$0.3	300%	$1.2	SWAG
	Bonding & Insurance		$0.5	50%	$0.8	Est. by finance
	Other		$0.5	35%	$0.7	
	Soft Costs		**$4.3**	**54%**	**$6.6**	
D	**Contingency**	15%	**$3.3**		**$4.3**	missing scope only
A+B+C+D	**INVESTMENT REQUIRED**		**$25.4** Likely case	**29%**	**$32.7** Worst case	

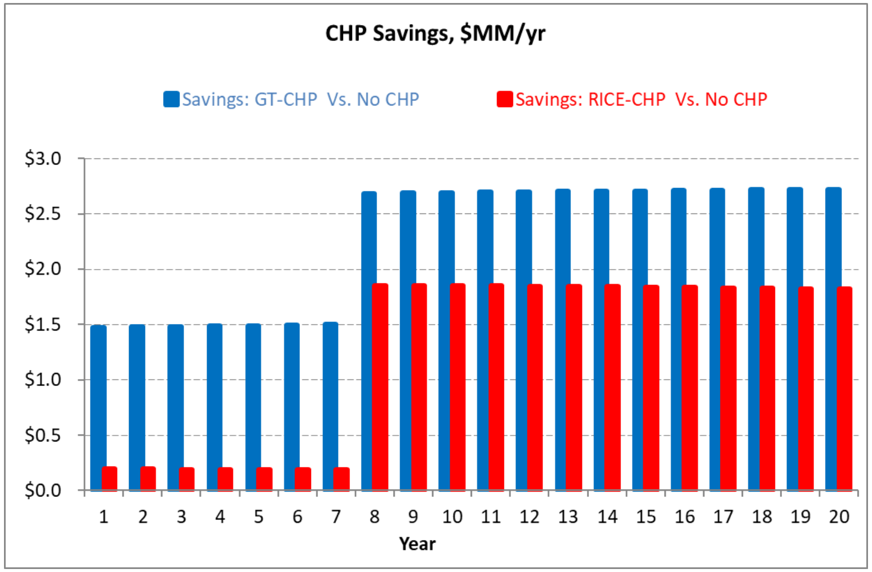




Graph projected cashflows to select microgrid configuration and risk-adjusted financing structure

OUTPUT	UNIT	VALUE	VALUE	VALUE
		No CHP	GT-CHP	RICE-CHP
Thermodynamic Metrics				
Efficiency	% LHV	-	80%	77%
Electrical Heat Rate	LHV MMBtu/MWh	-	5.5	5.2
Thermal Energy Rate	LHV $MMBtu/MMBtu_{th}$	-	2.1	2.9
Project Financing Structure				
25% Equity	$MM	-	$3.0	$2.1
75% Debt	$MM	-	$9.0	$6.4
100% Total Investment	**$MM**	-	**$12.0**	**$8.5**
Year 1 Costs				
Grid pwr + Fuel+OpEx	$MM	$6.7	$4.0	$4.8
Grid Pwr + Fuel+OpEx+Debt Service	$MM	$6.7	$5.2	$6.5
CHP advantage Vs. No-CHP	$MM	-	*$1.5*	*$0.2*
Lifetime Costs				
Grid pwr + Fuel+OpEx	$MM	$148	$94	$111
Grid Pwr + Fuel+OpEx+Debt Service	$MM	$148	$102	$123
CHP advantage Vs. No-CHP	$MM	-	*$46*	*$25*





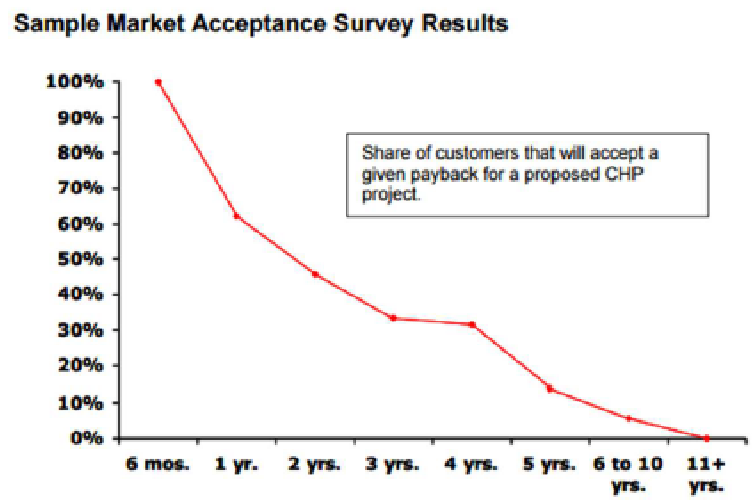
Sensitivity analysis quantifies risk and guides mitigation strategy

3.07 MW	10-yr Pjt ROI	Value of ORC power, c/KWh				
	20.8%	5.0	10.0	15.0	20.0	25.0
	$6.0	6.7%	28.5%	47.3%	65.3%	83.0%
WHP Installed CapEx	$6.5	4.8%	25.5%	43.2%	59.9%	76.3%
$MM	$7.0	3.2%	22.9%	39.6%	55.3%	70.6%
	$7.5	1.7%	20.6%	36.4%	51.2%	65.6%
	$8.0	0.3%	18.6%	33.7%	47.6%	61.2%
	$8.5	-0.9%	16.8%	31.2%	44.5%	57.3%

3.07 MW	10-yr Pjt ROI	Value of ORC power, c/KWh				
	20.8%	5.0	10.0	15.0	20.0	25.0
	2,840	-17.2%	-5.7%	2.8%	9.9%	16.2%
Ship Availability	3,840	-12.6%	0.5%	10.2%	18.7%	26.4%
Optg hrs/yr	4,840	-8.6%	5.8%	16.9%	26.7%	35.8%
	5,840	-5.1%	10.6%	23.1%	34.3%	44.9%
	6,840	-2.0%	15.1%	28.9%	41.6%	53.8%
	7,840	0.9%	19.3%	34.6%	48.8%	62.5%

3.07 MW	10-yr Pjt ROI	Value of ORC power, c/KWh				
	20.8%	5.0	10.0	15.0	20.0	25.0
	14.0%	-5.8%	9.6%	21.8%	32.7%	43.1%
Ht-to-Pwr. Efficiency	15.0%	-4.5%	11.5%	24.2%	35.7%	46.7%
%	16.0%	-3.2%	13.3%	26.6%	38.7%	50.2%
	17.0%	-2.0%	15.1%	28.9%	41.6%	53.8%
	18.0%	-0.8%	16.8%	31.2%	44.5%	57.3%
	19.0%	0.4%	18.5%	33.5%	47.4%	60.8%

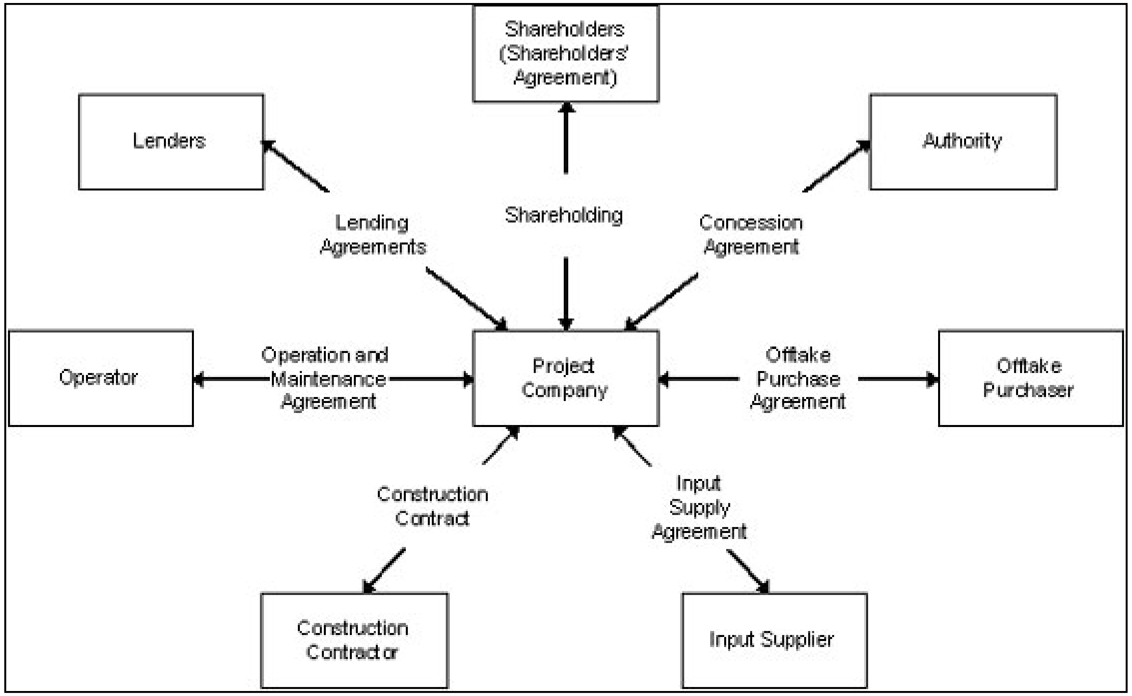
Capturing the value of resiliency helps deploy more projects



Tradeoffs: Cost Vs. Accuracy Vs. Time

ESTIMATE CLASS	ESTIMATE TYPE	PURPOSE	ACCURACY	PROJECT COMPLETION	COST & TIME
5	Order of Magnitude (OOM)	Initial Feasibility or screening	-50% to 100%	0%-to-1%	Free-to-$10,000 2-hours-to-3 days
4	Preliminary	Concept study or feasibility	-15% to 50%	1%-to-15%	$5,000-to-$50,000 2-days-to-5 weeks
3	Definitive	Budget, authorization or control	-10% to 30%	10%-to-40%	3%-to-5% of final CapEx 4-weeks-to-4 months
2	Detailed	Control or bid/tender	-5% to 20%	30%-to-70%	4%-to-10% of final CapEx 2-to-6 months
1	Check (Construction)	Bid/tender	-3% to 15%	50%-to-100%	5%-to-20% of final CapEx 3-to-12 months

Risk Mitigation = Project Success



A Special Purpose Vehicle (SPV) can deliver the project; provides a legal ring-fence

Pricing structure must be simple, transparent and equitable

Pjt. Delivery: EPC or EPCM?

CONTRACTING / PRICING STRATEGY

Clean water price = fixed + variable + margin

Fixed = f(CapEx, fixed O&M)

Variable = f(gas, grid power, variable O&M)

Margin = f(fixed fee)

ENWADEV ENERGY AND WATER DEVELOPMENT, LLC

C: How do I Operate & Maintain my microgrid?

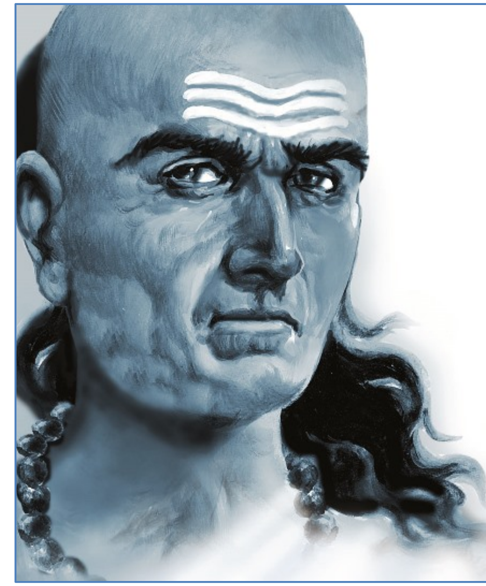
IDEA2019 The Energy for More Resilient Cities

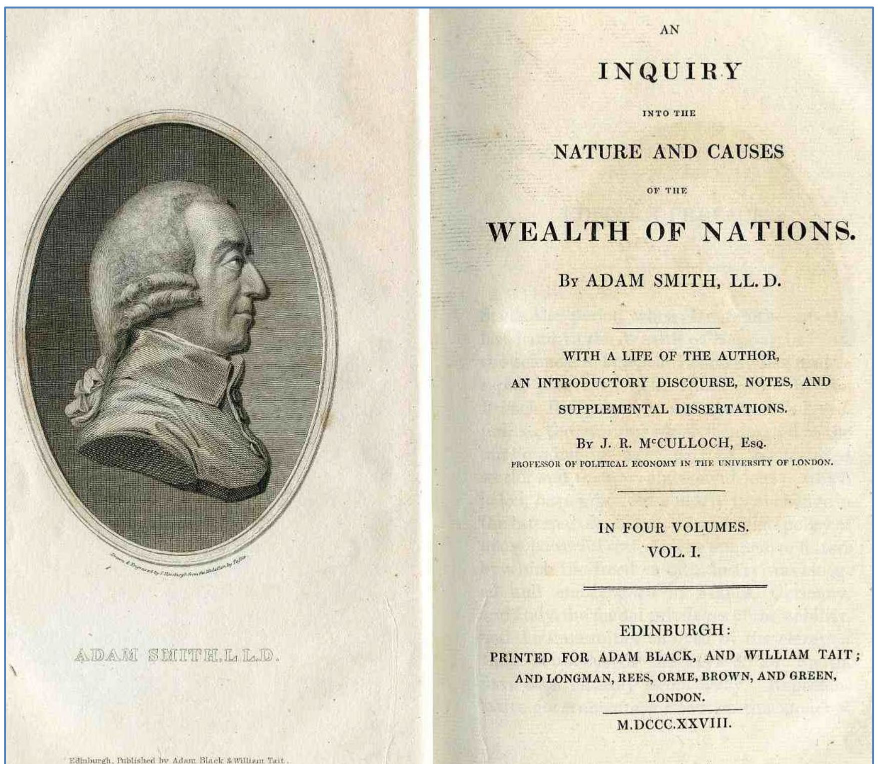
Economic 1st principle: *Focus on core competence.* Inference? *Outsource non-core needs*

Kautilya (aka. Chanakya, Indian royal advisor from 2,300 year ago):

In his "*Arthashastra*", he advised the kingdom's requirements be "outsourced" to citizens so "*each may excel at his task*".

The kingdom's prosperity depended only on external defense, internal security plus speedy & impartial justice.




ADAM SMITH, LL.D.

Edinburgh, Published by Adam Black & William Tait.

AN
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BY J. R. McCULLOCH, Esq.
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Adam Smith (18th century Scottish philosopher):

"It is not from the benevolence of the butcher, the brewer or the baker that we expect our dinner, but from their regard to their own interest"

Common Contract O&M commercial structures

Service Contract type	Typical Features	Costs & Benefit
Full Coverage	100% coverage of operations, maintenance, parts & material, emergency service etc…	High Budget certainty. Provider incentivized to minimize Repair & replacement costs
Full Labor	Labor + minimal maintenance. Parts & material, emergency service etc… on a T&M basis	Budget certainty and lower costs if asset owner able to manage some activities
Preventive Maintenance	Fixed fee covers scheduled maintenance hours + basic consumables	Lower upfront cost, lower budget certainty & medium Owner involvement
Inspection	Fixed fee covers "fly-by" visits and + a maintenance advisory	Very low upfront cost, low budget certainty & high Owner involvement

Project Development = Common sense + diligence. Recap principles

1. Set objectives & gather data
2. Conceptualize alternate configurations: technical & economic appraisal
3. Project development

Technical:	Configuration, engineering, procurement, construction
Legal:	Structure of contracting entities (LLC, S or C Corp etc…)
Commercial:	Contracts for fuel, power, O&M, grants & incentives
Environmental:	Permits
Financial:	Financial models, equity & debt
Risks & Mitigants:	Project Execution Plan (PEP)

4. Operations & Maintenance (O&M)

QUESTIONS?

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