Microgrid 2.0

Advancing Industry Growth

OCTOBER 29-31, 2018 ▼ BALTIMORE, MD

A Microgrid configured as a Boiler + a Back Pressure Steam Turbine (Blr. + BPST)

Agenda

Introduction

Microgrids – what, how and why?

Microgrid plus Combined Heat & Power (CHP) configured as a Boiler + Back Pressure Steam Turbine

Configuration, performance and economics

Project Development

Who is Energy & Water Development LLC?

Customized Energy and Water Development services for Industrial, Municipal & Commercial clients; 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:
Reliably deliver energy & water to the customer and maintain asset value for the owner

Assertions:

1. Efficiency *hedges* energy & water price volatility.

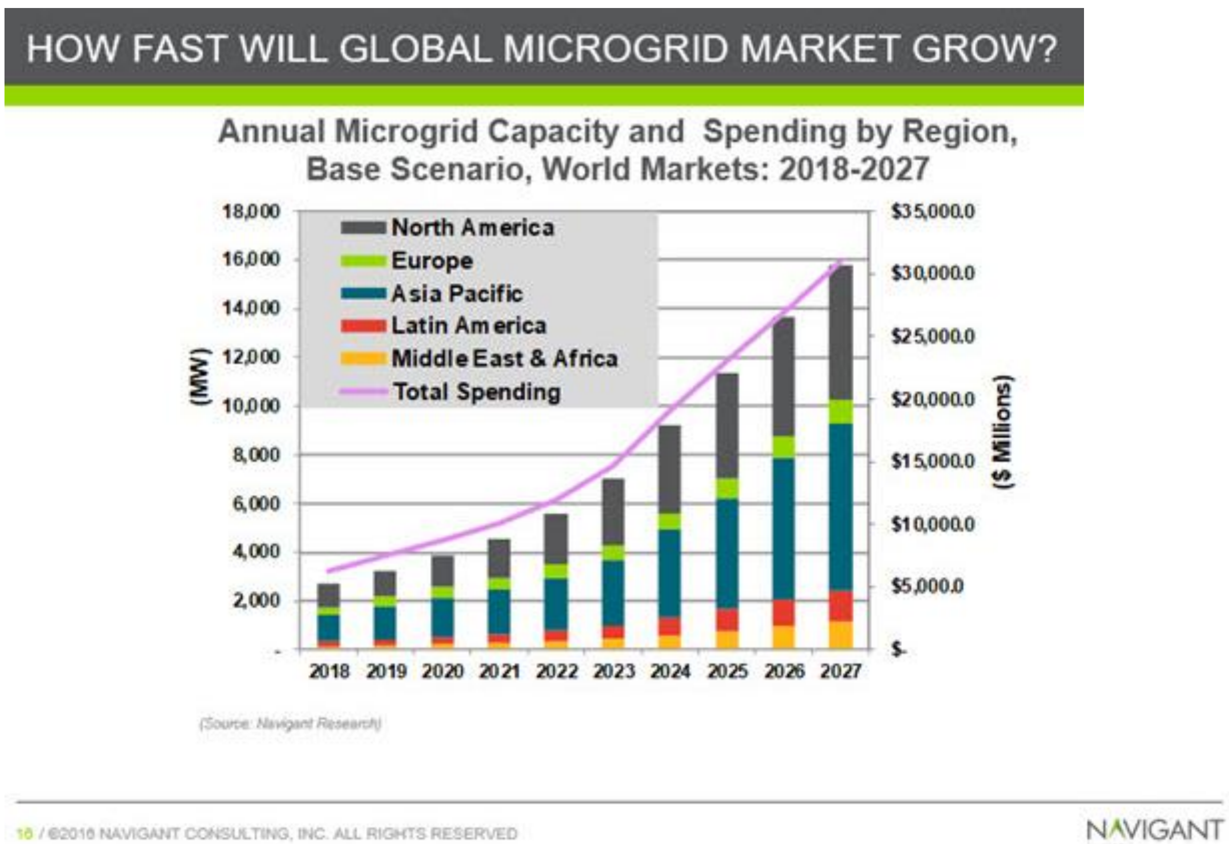
2. *Profitably* reduce Greenhouse Gas Emissions.

3. *No conflict* between your wallet and your conscience.

Microgrids – the market is growing

Low clearing prices emerging: in the US, solar is beginning to beat low cost fossil (2017)

More on this later



Renewables-Plus-Storage Projects are Clustered in Key Storage Regions Globally, 1.6 GW of Storage Paired with Renewables

Renewables-Plus-Storage Projects, Operational and Pipeline Storage

Global Rated Power in MW

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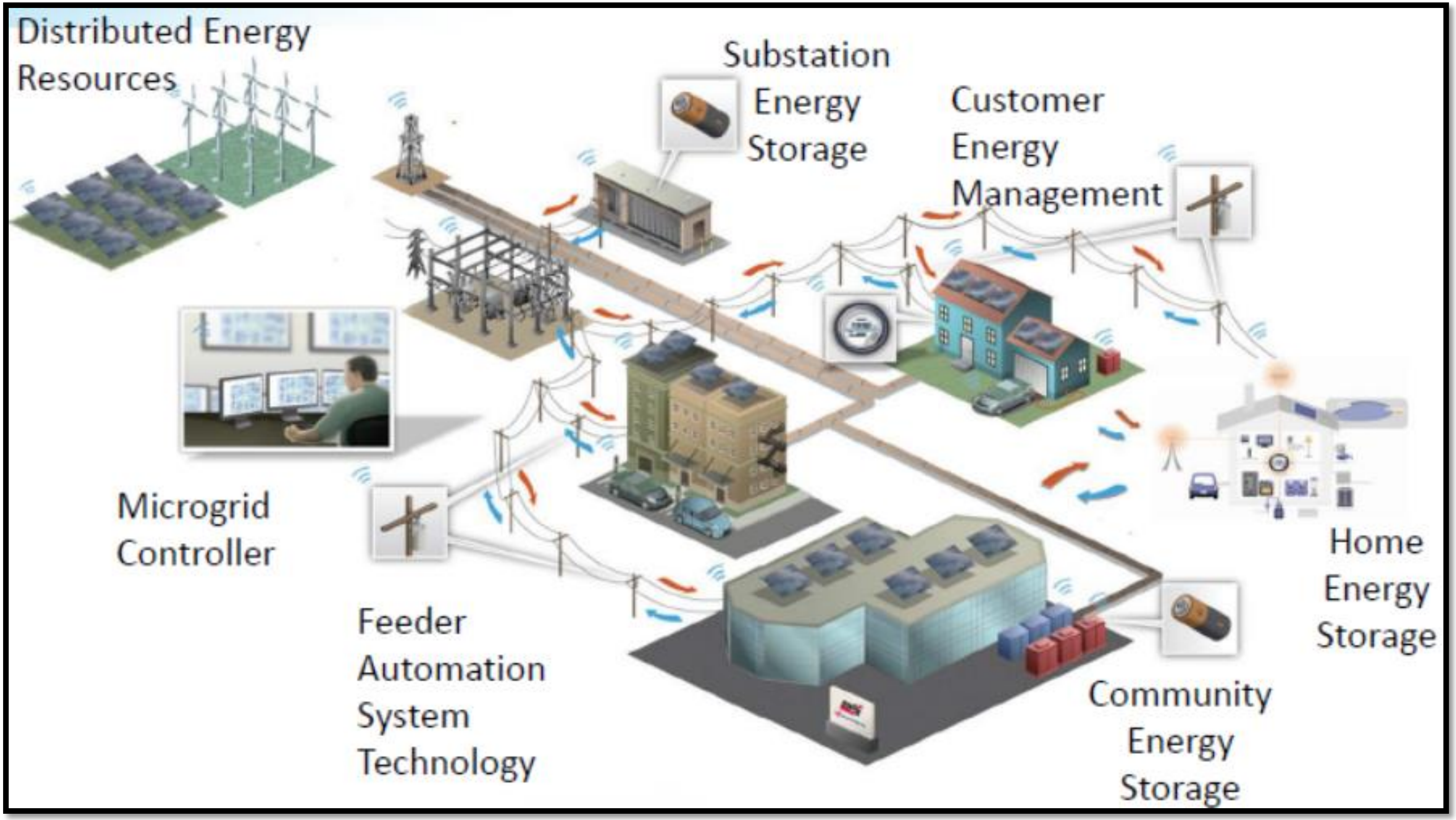
Microgrids – what are they?

A set of interconnected loads and distributed energy resources within defined electrical boundaries;
As a single controllable entity can stay grid-connected or operate in island mode.



Source: https://ilsr.org/report-mighty-microgrids/

Microgrids – what's often overlooked? Thermal energy!

Industrial and commercial customers often need thermal energy with electrical energy. Heat (Steam / hot water) is commonly supplied by a natural gas "package boiler"

A topping cycle natural gas Combined Heat & Power (CHP) system can supply site power & heat.

- Gas Turbines (GT), Reciprocating Engines (RE) are *power-first* CHP components and their waste heat is recycled into steam/hot water. High "power-to-heat" ratio

- Compared to package boilers, CHP has higher CapEx and OpEx; economics impacted by value of power relative to the cost of natural gas

Topping cycle GAS TURBINE COMBINED HEAT & POWER (CHP) SYSTEM

INPUT	UNIT	VALUE	COMMENT
Gross Capacity	$MW_{e\ gross}$	50	Available to grid / utility
CapEx	$/KWe	$1,600	f (MW, KV, Kpph, psig)
Par. Pwr	% of $MW_{e\ gross}$	4%	OK
Full load availability	%	95%	OK
Debt term	years	20	Project term
Interest rate	%	7%	assumed
O&M Costs			
Fixed O&M	% of CapEx	2.5%	typical - FTE, skg fund etc
Variable O&M	$/MWHr	$6	typical
Fuel & Performance			
Gas at Burner tip	$/MMBtu, HHV	$4.0	Hub + distribution
Heat Rate	Btu/KWhr, HHV	5,000	Typical

Topping cycle GAS TURBINE COMBINED HEAT & POWER (CHP) SYSTEM

OUTPUT	UNIT	VALUE	COMMENT
Investment required	$MM	$80	by equity investor
Capacity payment	$MM/yr	$8	by utility to equity investor
Capacity Pmt reqd.	$/KW/month	$12.6	$151 $K/MW-yr
Operating hours	hrs/yr	8,322	
Net power at user	MWe	48	
Net power exported	MWHr/yr	399,456	
Cost of power			
O&M	$/MWHr	$11.0	$4 $MM/yr
Fuel	$/MWHr	$20.0	$8 $MM/yr
Capital recovery	$/MWHr	$18.9	$8 $MM/yr
TOTAL	**$/MWHr**	**$49.9**	**$20 $MM/yr**

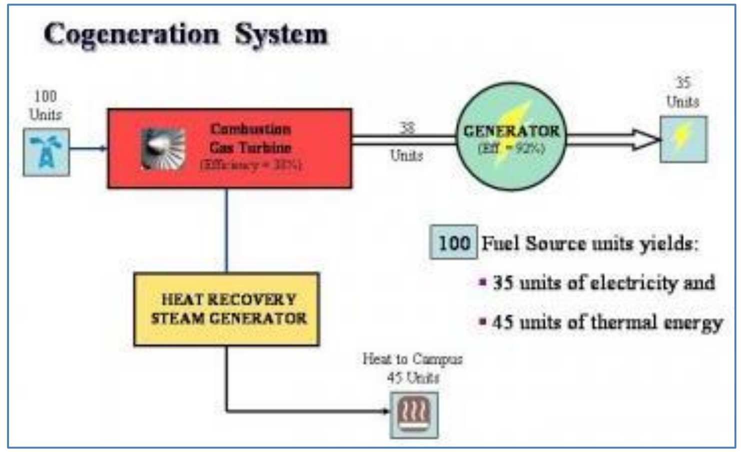
More on this later

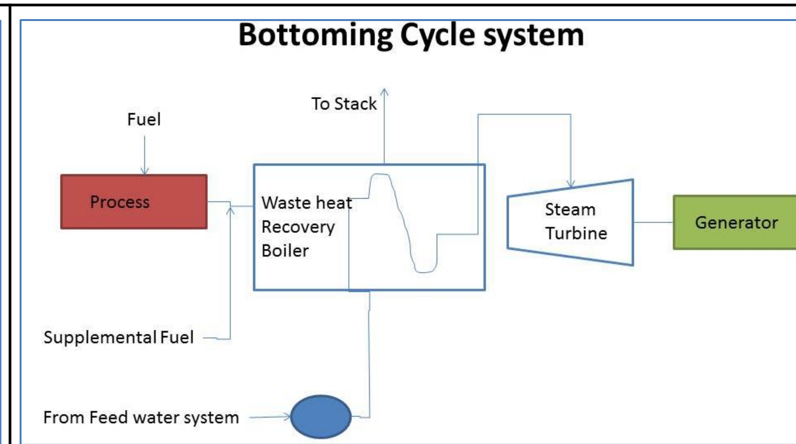
Why CHP? Efficiently deliver power and heat

“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

Primer on CHP "topping & bottoming" cycles





What	**Topping Cycle CHP**	**Bottoming Cycle CHP**
Characteristic	Power first, then heat	Heat first, then power
Power-to-heat ratio	Higher	Lower
Relative CapEx	Higher	Lower
Relative OpEx	Higher	Lower
*** Longer-term** economic fit to a "renewables" microgrid	**Lower**	**Higher**

* "Renewables" microgrid configured with (*sun, wind*) generation ***plus*** a Battery Energy Storage (BES)

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But…. longer-term concern with "topping cycle" CHP?

Long-term power price down-trend due to fossil-free renewables (wind, sun) + battery energy storage.

Conventional fossil power (coal, nuclear) are in trouble – uncompetitive even on an operating basis.

Large (500+ MW) Combined Cycle Gas Turbine (CCGT) plants are currently competitive….but for how long?

Topping cycle ("Power first") CHP is competitive, but……

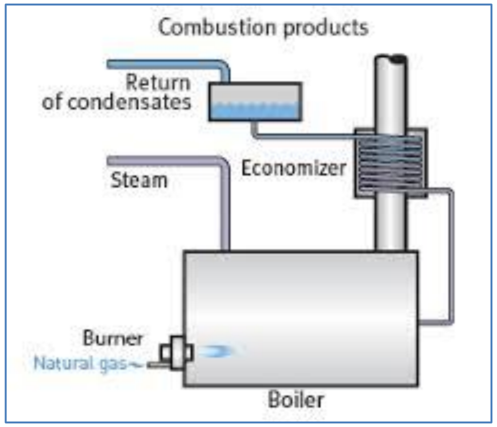
- ***Good***: Efficient (*Heat Rate ~5000 btu/kwh*).
- *Bad*: Investment gap ($/KW) between fossil-free renewables and fossil-fired CHP is narrowing.
- *Bad*: Operating cost ($/MWh) of topping cycle CHP trending higher than pure renewables.

Bottoming cycle CHP is a natural fit when there is a thermal load (low pressure steam or hot water).

A Combined Heat & Power (DF-CHP) system can also be configured as a High Pressure Steam Boiler tied to a Back Pressure Steam Turbine (Blr. + BPST)

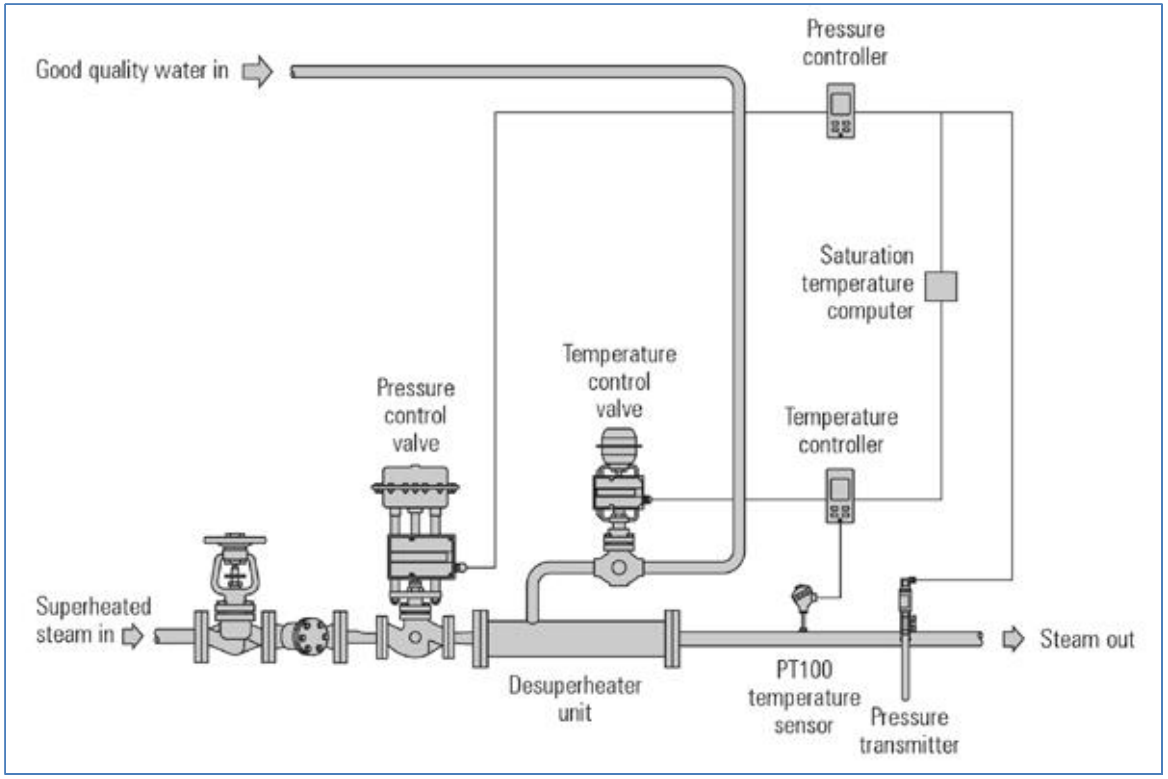
This low-cost, easily designed & installed CHP configuration improves the economics of a "conventional, renewables only" microgrid

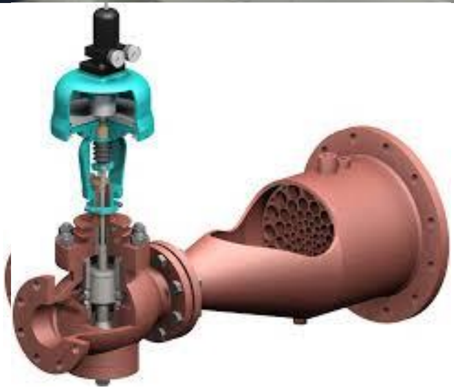
A picture is worth a 1000 words: Boiler, PRV & BPST



Gas "package" boiler: water in, steam out

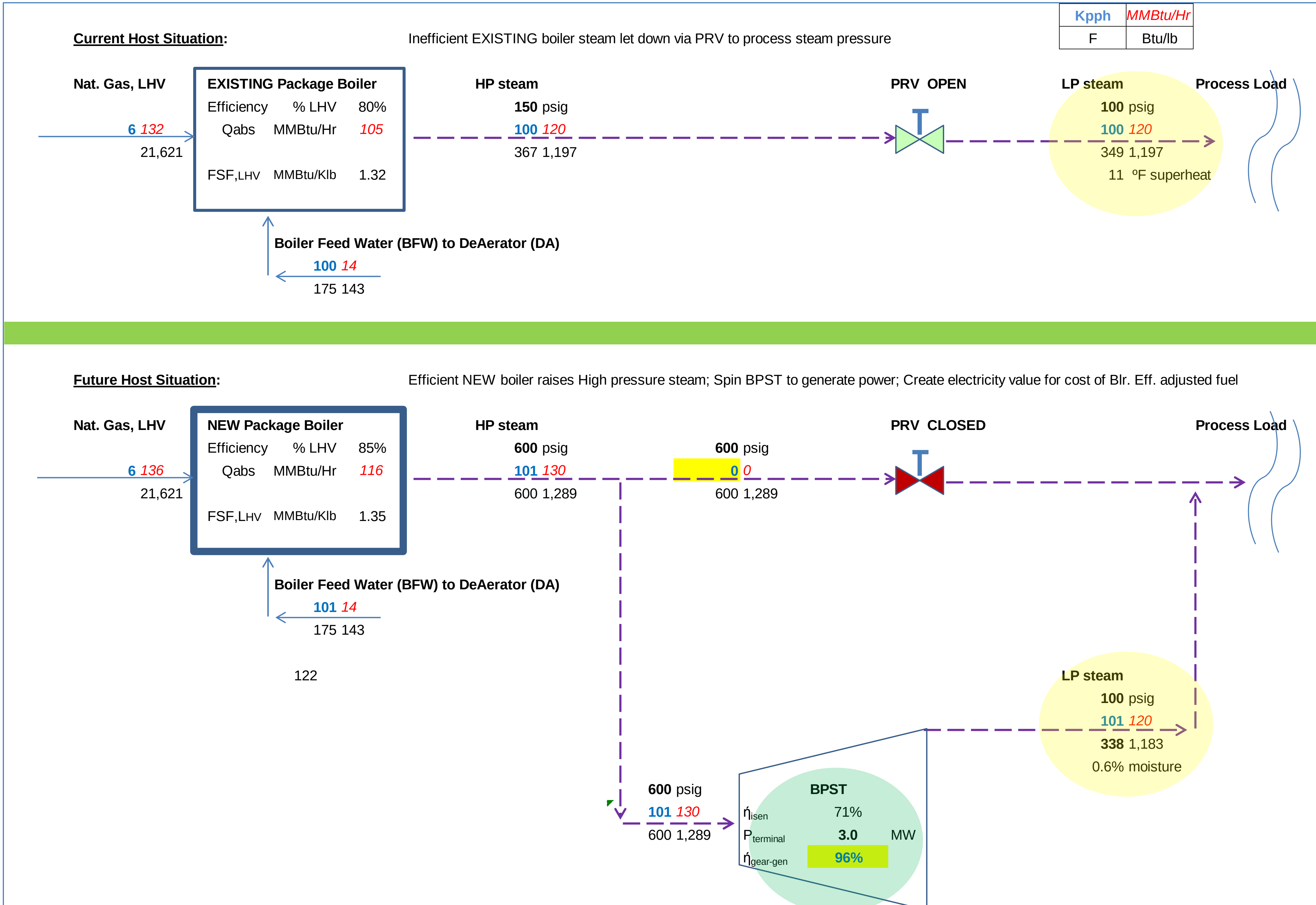
Back Pressure Steam Turbine (BPST): generates electric energy and creates economic value





Steam Pressure Reducing Valve (PRV): Increases Entropy; **wastes thermodynamic & economic value**.

Thermodynamics: Boiler only versus Boiler + BPT



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Economics: Boiler only versus Boiler + BPT

Incremental Investment	$K	**$3,000**
EBITDA value created	$K/yr	**$1,168**
"Mother Nature" Payback	years	**2.6**
GHG Emissions offset	mt CO_2/yr	**6,504**

BPST project power output	KW	**3,011**
CHP: Fuel cost of power	¢/KWHr	**1.7**
CHP Efficiency	% LHV	**85%**
CHP: Heat Rate	Btu/KWHr, LHV	**4,181**

INPUT PARAMETER	UNIT	VALUE	COMMENT	
Current Host situation				
All-in Electricity	¢/KWHr	6.0	Retail value	
Gas at burner tip, HHV	$/MMBtu, HHV	$4.00	Spk-sprd	4.4
NEW Pkge Blr + BPST System (incremental CapEx)				
Incremental CapEx: Installed	$K	$3,000	SWAG =f(scope)	
BPST: Isen. Eff.	%	71%	multi-stge BPT	
BPST: All-in O&M	¢/KWHr	0.70	assumed	
New Blr: Efficiency	% LHV	85%	typical	
New Blr: Hdr. Stm	psig	600	selected	
	F	600	111	ºF sup.ht
New Blr: All-in O&M	¢/Klb	50	assumed	
Existing boiler				
Efficiency	% LHV	80%	assumed	
Boiler Feedwater	F	175	assumed	
Header steam	psig	150	assumed	
	F	367	1	ºF sup.ht
Blr: All-in O&M	¢/Klb	50	assumed	
Process Steam LOAD				
Process steam	psig	100.0	assumed	
	Kpph	100.0	assumed	
Full Load Optg Hrs	Hrs/yr	8,322	assumed	
Grid GHG emissions	lb CO_2/MWHr	750	e-GRID data	

OUTPUT PARAMETER	UNIT	VALUE			
		BEFORE	**AFTER**	**CHANGE**	**% Chge**
Existing Boiler Fuel	MMBtu/yr, LHV	*1,096,125*	**0**		
NEW Boiler Fuel	MMBtu/yr, LHV	**0**	*1,134,766*		
Net Change in Blr fuel	**MMBtu/yr, LHV**			***38,640***	**4%**
Power	**MWHr/yr**	**0**	**25,056**	**25,056**	#DIV/0!
Process steam	MMBtu/Hr	*120*	*120*	***0***	0%
	Kpph	**100**	**101**	**1**	**1.2%**
Value of Displaced Power	$K/yr	**$0**	$1,503	$1,503	
EXISTING Blr system O&M	$K/yr	$416	**$0**	$416	
NEW Blr system O&M	$K/yr	**$0**	$421	($421)	
BPST system O&M	$K/yr	**$0**	$175	($175)	
Gas Cost	$K/yr	$4,385	$4,539	($155)	
EBITDA	**$K/yr**			**$1,168**	
<u>GHG emissions</u>					
EXISTING Blr. Nat. gas	mt CO_2/yr	57,796	0	(57,796)	
NEW Blr. Nat. gas	mt CO_2/yr	0	59,833	59,833	
Offset grid power	mt CO_2/yr	**0**	(8,542)	(8,542)	
TOTAL	**mt CO_2/yr**	**57,796**	**51,291**	(6,504)	**-11%**

Economics: Sensitivity of key parameters: cost of displaced grid power, Project incremental CapEx

Boiler+BPT Payback "Hurdle"	years	3.0

MN Payback, yrs		Gas at burner tip, $/MMBtu, HHV				
	2.6	$2.0	$3.0	$4.0	$5.0	$6.0
	5.0	3.0	3.1	3.3	3.4	3.6
All-in Electı	5.5	2.7	2.8	2.9	3.0	3.1
¢/KWHr	6.0	2.4	2.5	2.6	2.7	2.7
	6.5	2.2	2.3	2.3	2.4	2.5
	7.0	2.0	2.1	2.1	2.2	2.2
	7.5	1.9	1.9	1.9	2.0	2.0

MN Payback, yrs		Gas at burner tip, $/MMBtu, HHV				
	2.6	$2.0	$3.0	$4.0	$5.0	$6.0
	$2,500	2.0	2.1	2.1	2.2	2.3
CapEx inst	$2,750	2.2	2.3	2.4	2.4	2.5
$K	$3,000	2.4	2.5	2.6	2.7	2.7
	$3,250	2.6	2.7	2.8	2.9	3.0
	$3,500	2.8	2.9	3.0	3.1	3.2
	$3,750	3.0	3.1	3.2	3.3	3.4

Boiler+BPT Payback "Hurdle"	years	3.0

EBITDA, $K/yr		Gas at burner tip, $/MMBtu, HHV				
	$1,168	$2.0	$3.0	$4.0	$5.0	$6.0
	5.0	$995	$957	$918	$879	$841
All-in Electricity	5.5	$1,121	$1,082	$1,043	$1,005	$966
¢/KWHr	6.0	$1,246	$1,207	$1,168	$1,130	$1,091
	6.5	$1,371	$1,332	$1,294	$1,255	$1,216
	7.0	$1,496	$1,458	$1,419	$1,380	$1,342
	7.5	$1,622	$1,583	$1,544	$1,506	$1,467

EBITDA, $K/yr		Gas at burner tip, $/MMBtu, HHV				
	$1,168	$2.0	$3.0	$4.0	$5.0	$6.0
	$2,500	$1,246	$1,207	$1,168	$1,130	$1,091
CapEx installed	$2,750	$1,246	$1,207	$1,168	$1,130	$1,091
$K	$3,000	$1,246	$1,207	$1,168	$1,130	$1,091
	$3,250	$1,246	$1,207	$1,168	$1,130	$1,091
	$3,500	$1,246	$1,207	$1,168	$1,130	$1,091
	$3,750	$1,246	$1,207	$1,168	$1,130	$1,091

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Economics: Sensitivity of key parameters: site steam load and full load operating hours

Boiler+BPT Payback "Hurdle"	**years**	**3.0**

MN Payback, yrs		**Gas at burner tip, $/MMBtu, HHV**				
	2.6	**$2.0**	$3.0	$4.0	$5.0	$6.0
	80	3.0	3.1	3.2	3.3	3.4
Process st	88	2.7	2.8	2.9	3.0	3.1
Kpph	96	2.5	2.6	2.7	2.8	2.9
	104	2.3	2.4	2.5	2.6	2.6
	112	2.2	2.2	2.3	2.4	2.5
	120	2.0	2.1	2.1	2.2	2.3

MN Payback, yrs		**Gas at burner tip, $/MMBtu, HHV**				
	2.6	**$2.0**	$3.0	$4.0	$5.0	$6.0
	5,500	3.6	3.8	3.9	4.0	4.2
Full Load C	6,050	3.3	3.4	3.5	3.7	3.8
Hrs/yr	6,600	3.0	3.1	3.2	3.3	3.5
	7,150	2.8	2.9	3.0	3.1	3.2
OK	7,700	2.6	2.7	2.8	2.9	3.0
	8,250	2.429	2.507	2.590	2.678	2.773

Boiler+BPT Payback "Hurdle"	**years**	**3.0**

EBITDA, $K/yr		**Gas at burner tip, $/MMBtu, HHV**				
	$1,168	**$2.0**	$3.0	$4.0	$5.0	$6.0
	80	$1,246	$1,207	$1,168	$1,130	$1,091
Process steam	88	$1,246	$1,207	$1,168	$1,130	$1,091
Kpph	96	$1,246	$1,207	$1,168	$1,130	$1,091
	104	$1,246	$1,207	$1,168	$1,130	$1,091
	112	$1,246	$1,207	$1,168	$1,130	$1,091
	120	$1,246	$1,207	$1,168	$1,130	$1,091

EBITDA, $K/yr		**Gas at burner tip, $/MMBtu, HHV**				
	$1,168	**$2.0**	$3.0	$4.0	$5.0	$6.0
	5,500	$823	$798	$772	$747	$721
Full Load Optg	6,050	$906	$878	$849	$821	$793
Hrs/yr	6,600	$988	$957	$927	$896	$865
	7,150	$1,070	$1,037	$1,004	$971	$938
	7,700	$1,153	$1,117	$1,081	$1,045	$1,010
	8,250	$1,235	$1,197	$1,158	$1,120	$1,082

Boiler + BPST integrates into a “renewables”” microgrid

Benefit to the investor / owner
BPST payback < 3-yrs (IRR > 30%)

Extremely low “fuel cost of power” makes a bottoming cycle CHP configured as a boiler + BPT another source of power for a thermal customer considering a “renewables” microgrid.

Reliable onsite power supply. BPST maintain their efficiency across the load curve from 100% to 20% of nameplate; hence over/under sizing is *less* of a concern

Benefit to Grid
Local grid stability including power factor support and reduced I2R line loss
Balance variable power from wind and solar, thus speed renewable energy deployment

Benefit to society
Reduced pollution and profitable lowering of greenhouse gas emissions

Project Development: common sense + due diligence

1. Set objectives & gather data; conceptualize configurations; technical & economic appraisal

2. 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. Project Delivery; Long-term Operations & Maintenance

TAILWINDS	HEADWINDS
Tried & true technology CHP recognized as a proven technology	**Inertia and unfamiliarity** Compared to CHP, boilers are "tried and true"
10% Investment Tax Credit (ITC) Reduce CapEx; increase Return on Investment (ROI)	**Upfront investment** Slightly greater CapEx compared to boiler only.
Accelerated depreciation Increases Return on Equity (ROE)	**Air permit** MACT pollution control regulations allow retaining current air permit. CHP reduces pollution, yet requires a new permit
Value of redundancy, resiliency & reliability	**Standby & exit charges** Imposed by some utilities before allowing CHP systems to interconnect with the grid.

Questions?

Suresh Jambunathan,
Owner & CEO
Energy and Water Development LLC
www.energywaterdev.com

Cell: 630-335-4544
E-mail: enwadev@gmail.com; Suresh.Jambunathan@gmail.com

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