The Microgrid Revolution

Campus and Urban Microgrid Economics: Exploring What it Means

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Microgrids Convergence conference,
San Mateo Marriott, San Francisco Airport

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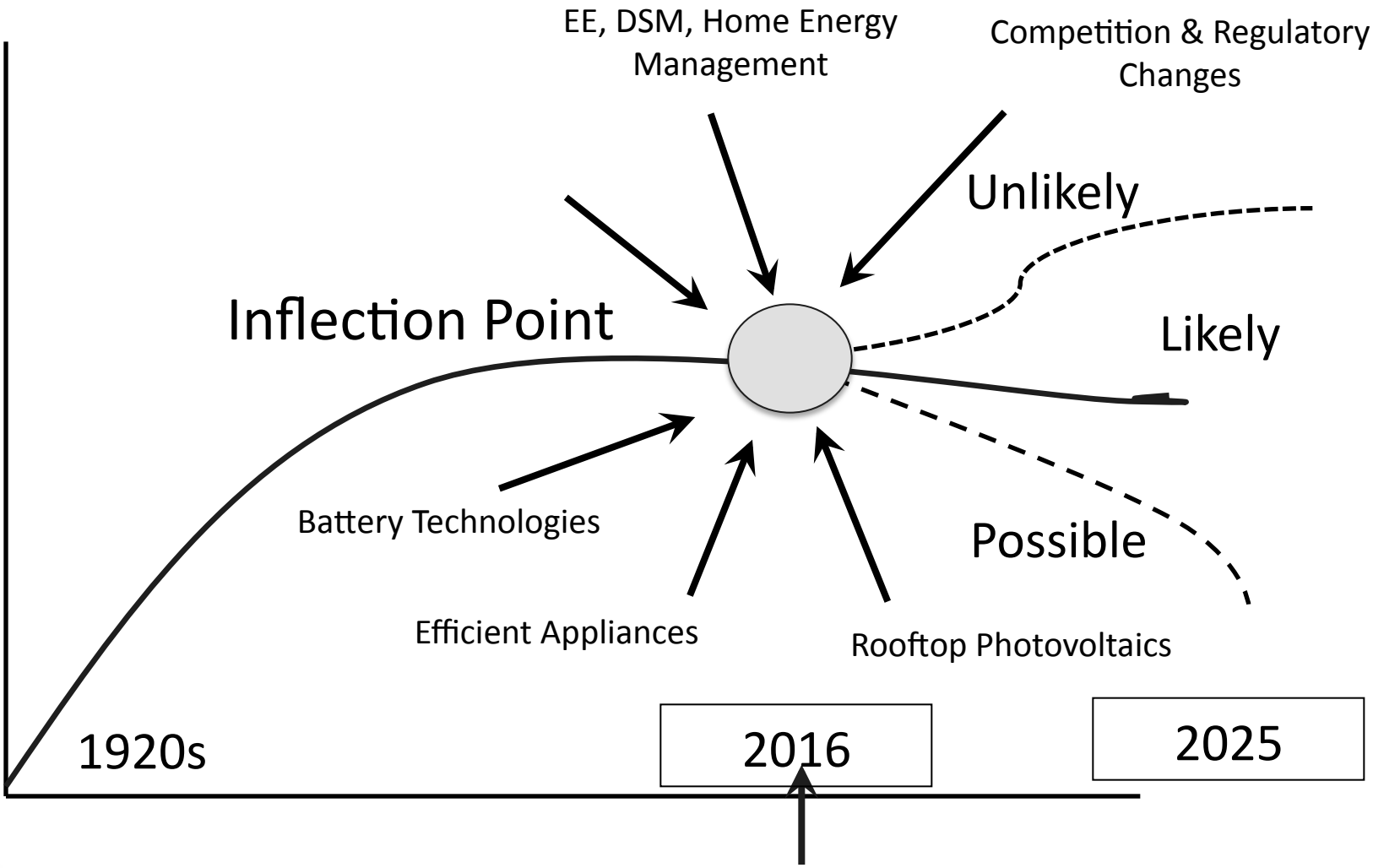
"Dear Electric Company CEO: Merry Xmas"

"Your bankers never told you this, the ratings agency hasn't downgraded your bonds and you'll never convince your board of directors. So, let's add really stockholder- friendly advice. Sell the company now for top dollar. .... Right now, yield starved investors, infrastructure funds and utilities looking for "earnings accretive" growth-by-acquisition want properties. Sell now while your business still looks attractive and low interest rates make deals look good."

– *Leonard Hyman & William Tilles, Dec 22, 2015*

http://oilprice.com/Energy/Energy-General/Dear-Electric-Company-CEO-Merry-Xmas-and-Cut-the-Dividend.html

Context: Industry at inflection point



Microgrids: Are They Economical?

What's the $/kWh of microgrid electricity? For a ~1 MW microgrid? Compared to grid pricing at the location?

Until December 2014, it appears, ***no one knew!***

We decided to model IIM K's academic hill, and a homeowners' association in San Diego, California

Today's industry structure obsolete

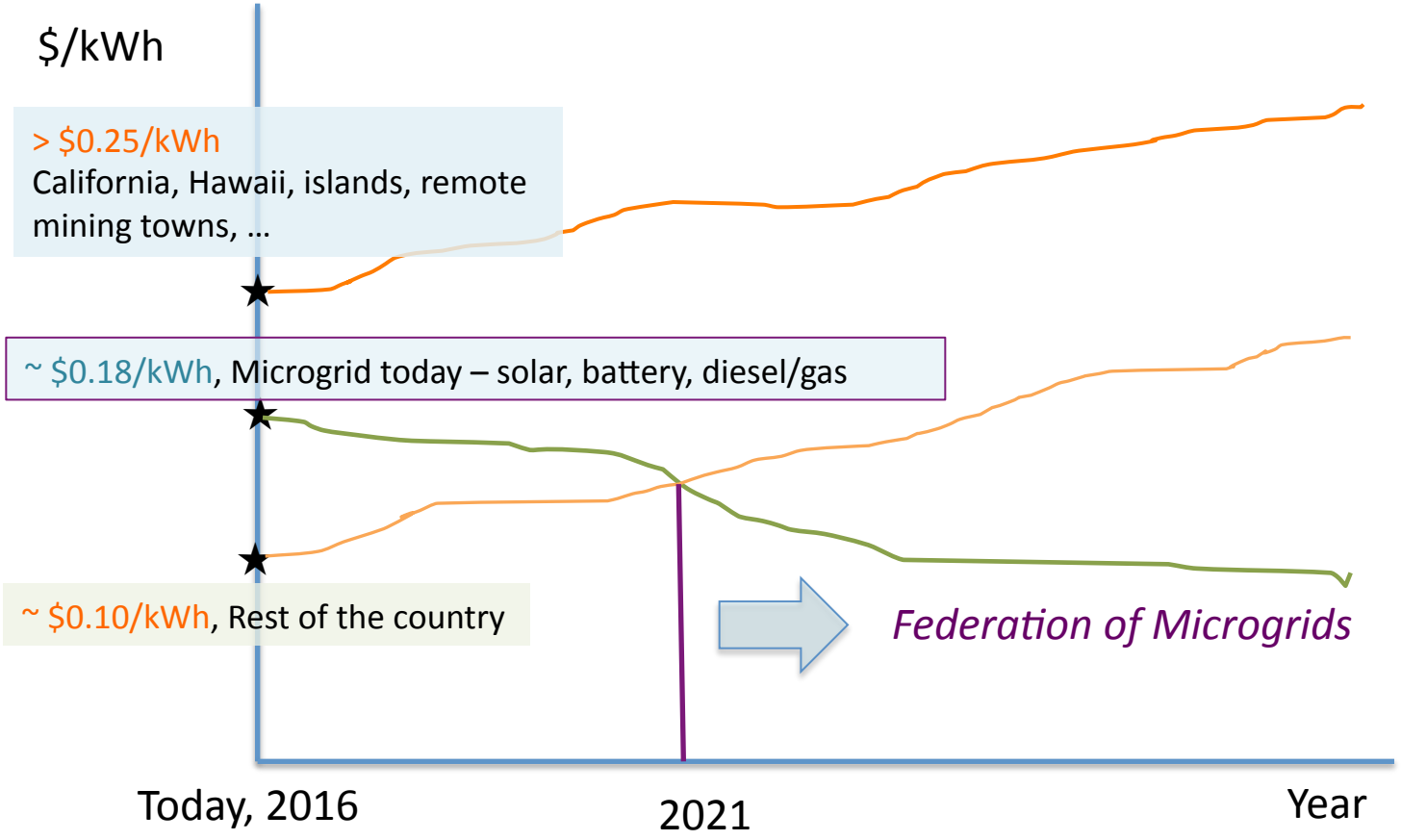
- Barriers to entry have fallen
- Scale economics not necessary for low unit costs
- Natural monopoly dead
- Industry boundaries breached

IIM K campus – aerial view

11 kV lines enter the campus

Academic hill: IIM Kozhikode, India

Conclusion: What Microgrid economics means



Strategy: Identify, lock up sites *today.* Opportunity costs of delay

Modeling difficult

- Electrical engineering, plus
- Financial modeling
- Project finance
- Demand side management and control
- Systems view – what happens if we add another generating source?

- *See my article,*
  Microgrid Economics: It Takes a Village, a University, and a Ship, ***Renewable Energy World,*** *Sep 30, 2014.*

What we did at IIM K, 2014-15

- Given design parameters, create a “plug and reveal” model, mask all financial complexity
- The model should yield $/kWh, NPV, Breakeven for a given project
- This we have done

Homeowners' association, San Diego, CA

~ 120 homes

~ 1 MW average load

Sufficient rooftop and open space

Substation here

Homeowners' association as microgrid

Can a microgrid of ~ 20 homes be viable? Of 120 homes?

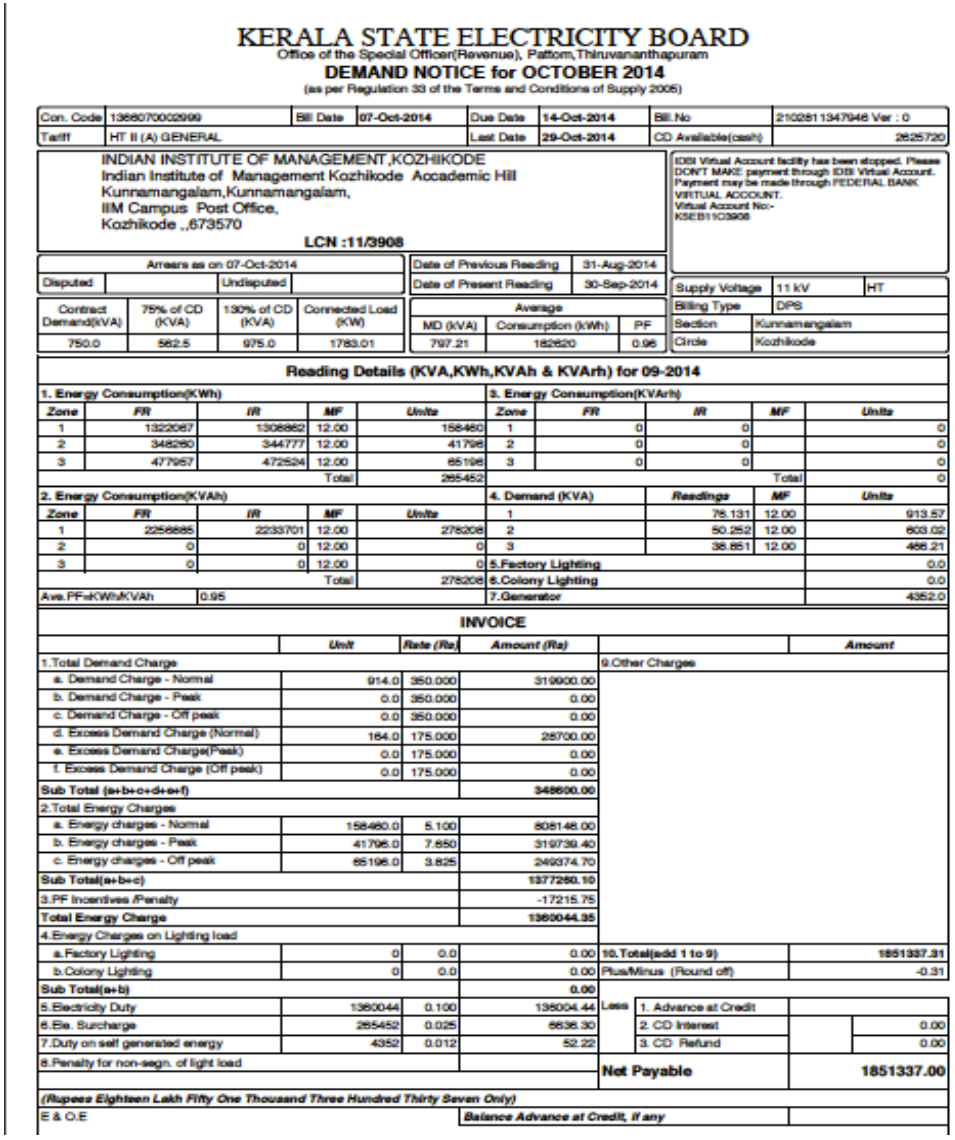
Most homes have enough roof for a 5 kW solar system each

Homeowners Association: 120 homes, CA

Revenue calculation	M1Y1	M2Y1	M3Y1	M4Y1	M5Y1	M6Y1	M7Y1	M8Y1	M9Y1	M10Y1	M11Y1	M12Y1
Base Home, kWh, 2013	559	600	535	498	499	480	521	474	494	456	472	616
Electricity Bill	$ 107.00	$ 134.00	$ 118.00	$ 92.00	$ 98.00	$ 88.00	$ 102.00	$ 88.00	$ 103.00	$ 93.00	$ 95.00	$ 139.00
Rate	$ 0.19	$ 0.22	$ 0.22	$ 0.18	$ 0.20	$ 0.18	$ 0.20	$ 0.19	$ 0.21	$ 0.20	$ 0.20	$ 0.23
Regular consumption /base home consumption	170%	170%	170%	170%	170%	170%	170%	170%	170%	170%	170%	170%
Number of homes served by the microgrid	120	120	120	120	120	120	120	120	120	120	120	120
Revenue	$ 21,828.00	$ 27,336.00	$ 24,072.00	$ 18,768.00	$ 19,992.00	$ 17,952.00	$ 20,808.00	$ 17,952.00	$ 21,012.00	$ 18,972.00	$ 19,380.00	$ 28,356.00

Revenue calculation	M1Y1	M2Y1	M3Y1	M4Y1	M5Y1	M6Y1	M7Y1	M8Y1	M9Y1	M10Y1	M11Y1	M12Y1
Base Home, kWh, 2013	559	600	535	498	499	480	521	474	494	456	472	616
Electricity Bill	$ 156.52	$ 168.00	$ 149.80	$ 139.44	$ 139.72	$ 134.40	$ 145.88	$ 132.72	$ 138.32	$ 127.68	$ 132.16	$ 172.48
Rate	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28	$ 0.28
Regular consumption /base home consumption	170%	170%	170%	170%	170%	170%	170%	170%	170%	170%	170%	170%
Number of homes served by the microgrid	120	120	120	120	120	120	120	120	120	120	120	120
Revenue	$ 31,930.08	$ 34,272.00	$ 30,559.20	$ 28,445.76	$ 28,502.88	$ 27,417.60	$ 29,759.52	$ 27,074.88	$ 28,217.28	$ 26,046.72	$ 26,960.64	$ 35,185.92

Benchmark:
Campus Electricity Bill



KERALA STATE ELECTRICITY BOARD

Office of the Special Officer(Revenue), Pattom,Thiruvananthapuram

DEMAND NOTICE for OCTOBER 2014

(as per Regulation 33 of the Terms and Conditions of Supply 2005)

Con. Code	1366070002999	Bill Date	07-Oct-2014	Due Date	14-Oct-2014	Bill.No	2102811347946 Ver : 0
Tariff	HT II (A) GENERAL			Last Date	29-Oct-2014	CD Available(cash)	2625720

INDIAN INSTITUTE OF MANAGEMENT,KOZHIKODE
Indian Institute of Management Kozhikode Accademic Hill
Kunnamangalam,Kunnamangalam,
IIM Campus Post Office,
Kozhikode ,,673570

LCN :11/3908

IDBI Virtual Account facility has been stopped. Please DON'T MAKE payment through IDBI Virtual Account. Payment may be made through FEDERAL BANK VIRTUAL ACCOUNT.
Virtual Account No:-
KSEB11C3908

Arrears as on 07-Oct-2014		Date of Previous Reading	31-Aug-2014
Disputed	Undisputed	Date of Present Reading	30-Sep-2014

Contract Demand(kVA)	75% of CD (KVA)	130% of CD (KVA)	Connected Load (KW)
750.0	562.5	975.0	1783.01

Average		
MD (kVA)	Consumption (kWh)	PF
797.21	182620	0.96

Supply Voltage	11 kV	HT	
Billing Type	DPS		
Section	Kunnamangalam		
Circle	Kozhikode		

Reading Details (KVA,KWh,KVAh & KVArh) for 09-2014

1. Energy Consumption(KWh)

Zone	FR	IR	MF	Units
1	1322067	1306882	12.00	158460
2	348290	344777	12.00	41796
3	477957	472524	12.00	65196
		Total		265452

2. Energy Consumption(KVAh)

Zone	FR	IR	MF	Units
1	2256885	2233701	12.00	278208
2	0	0	12.00	0
3	0	0	12.00	0
		Total		278208
Ave.PFwKWh/KVAh	0.95			

3. Energy Consumption(KVArh)

Zone	FR	IR	MF	Units
1	0	0		0
2	0	0		0
3	0	0		0
			Total	0

4. Demand (KVA)

	Readings	MF	Units
1	76.131	12.00	913.57
2	50.252	12.00	603.02
3	38.851	12.00	466.21
5.Factory Lighting			0.0
6.Colony Lighting			0.0
7.Generator			4352.0

INVOICE

	Unit	Rate (Rs.)	Amount (Rs)		Amount
1.Total Demand Charge				9.Other Charges	
a. Demand Charge - Normal	914.0	350.000	319900.00		
b. Demand Charge - Peak	0.0	350.000	0.00		
c. Demand Charge - Off peak	0.0	350.000	0.00		
d. Excess Demand Charge (Normal)	164.0	175.000	28700.00		
e. Excess Demand Charge(Peak)	0.0	175.000	0.00		
f. Excess Demand Charge (Off peak)	0.0	175.000	0.00		
Sub Total (a+b+c+d+e+f)			**348600.00**		
2.Total Energy Charges					
a. Energy charges - Normal	158460.0	5.100	808146.00		
b. Energy charges - Peak	41796.0	7.650	319739.40		
c. Energy charges - Off peak	65196.0	3.825	249374.70		
Sub Total(a+b+c)			**1377260.10**		
3.PF Incentives /Penalty			-17215.75		
Total Energy Charge			**1360044.35**		
4.Energy Charges on Lighting load					
a.Factory Lighting	0	0.0	0.00	**10.Total(add 1 to 9)**	**1851337.31**
b.Colony Lighting	0	0.0	0.00	Plus/Minus (Round off)	-0.31
Sub Total(a+b)			**0.00**		
5.Electricity Duty	1360044	0.100	136004.44	Less 1. Advance at Credit	
6.Ele. Surcharge	265452	0.025	6636.30	2. CD Interest	0.00
7.Duty on self generated energy	4352	0.012	52.22	3. CD Refund	0.00
8.Penalty for non-segn. of light load				**Net Payable**	**1851337.00**

(Rupees Eighteen Lakh Fifty One Thousand Three Hundred Thirty Seven Only)

E & O.E

Balance Advance at Credit, if any

Load Profile - Campus

		KVA				Total		
Date	**Time**	**R**	**Y**	**B**				
13/10/2014	2.00. p.m.	2.057	2.217	2.251		2.00. p.m.	652.5	**13/10/2014**
	2.20.p.m.	2.098	2.276	2.199		2.20.p.m.	657.3	
	2.40.p.m.	2.112	2.261	2.294		2.40.p.m.	666.7	
	3.00.p.m.	2.212	2.305	2.397		3.00.p.m.	691.4	
	3.20.p.m.	2.153	2.283	2.288		3.20.p.m.	672.4	
	3.40.p.m	2.126	2.290	2.274		3.40.p.m	669	
	4.00.p.m.	2.208	2.330	2.321		4.00.p.m.	685.9	
	4.20.p.m.	2.303	2.309	2.533		4.20.p.m.	714.5	
	4.40.p.m.	2.272	2.337	2.404		4.40.p.m.	701.3	
	5.00.p.m.	2.198	2.332	2.409		5.00.p.m.	693.9	
	5.20.p.m.	1.819	1.906	1.894		5.20.p.m.	561.9	
	5.40.p.m.	1.672	1.836	1.782		5.40.p.m.	529	
	6.00.p.m.	1.619	1.802	1.766		6.00.p.m.	518.7	
	6.20.p.m.	2.069	2.192	2.239		6.20.p.m.	650	
	6.40.p.m.	2.008	2.227	2.221		6.40.p.m.	645.6	
	7.00.p.m.	1.834	2.055	2.01		7.00.p.m.	589.9	
	7.20.p.m.	2.438	2.425	2.378	DG2	7.20.p.m.	724.1	
	7.40.p.m.	1.521	1.417	1.46		7.40.p.m.	439.8	
	8.00.p.m.	1.798	2.074	1.928		8.00.p.m.	580	
	8.20.p.m.	2.067	2.362	2.324		8.20.p.m.	675.3	
	8.40.p.m.	2.036	2.281	2.313		8.40.p.m.	663	
	9.00.p.m.	2.109	2.308	2.275		9.00.p.m.	669.2	
	9.20.p.m.	1.903	2.158	2.143		9.20.p.m.	620.4	
	9.40.p.m.	1.949	2.126	2.181		9.40.p.m.	625.6	
	10.00.p.m.	1.819	2.059	2.073		10.00.p.m.	595.1	
	10.20.p.m.	1.488	1.675	1.619		10.20.p.m.	478.2	
	10.40.p.m.	1.591	1.753	1.760		10.40.p.m.	510.4	
	11.00.p.m.	1.283	1.302	1.377		11.00.p.m.	396.2	
	11.20.p.m.	1.268	1.325	1.347		11.20.p.m.	394	
	11.40.p.m.	1.236	1.290	1.345		11.40.p.m.	387.1	
14/10/2014	12.00.a.m.	1.201	1.263	1.251		12.00.a.m.	371.5	**14/10/2014**
	12.20.a.m.	1.189	1.204	1.221		12.20.a.m.	361.4	

Load Profile – how does it vary by location? By facility? What is the microgrid economics of:

- Hospitals
- Airports
- Office buildings
- Residential housing
- Malls …

First order design – heuristics-based

Load Profile		Max KW
6-9 AM	3 hrs	500
9 AM- 2 PM	5 hrs	700
2 - 5 PM	3 hrs	900
5 PM- 6 AM	13 hrs	500

Detailed load profile in another sheet

Average load	512,000	W
Peak Load (900 kW) ~	1,000,000	W
Total KWH demand in a day	10,944,896	Wh
Total KWH produced/ generated in a day	11,789,896	Wh

10 year battery, 25 year solar panels, straight line depreciation, 7.5% interest rate, …

How much solar capacity, costs?

SOLAR (direct peak energy sourcing & charging)			
Sunlight available average per day(9 AM- 2 PM)		5	hrs
Energy generation with excess capacity		1,900,000	Wh
Energy power from panel		1,731,000	Wh
Excess generation (5 hour Excess generation)		845,000	
Solar panel rating		300	W
Number of panels		6,333	
Cost (per piece) (Hyundai)	$	250.00	
Total cost	**$**	**1,266,666.67**	

Inverter, battery, diesel generator, and fuel costs

INVERTER			
Maximum inverter rating		800,000	W
Unit inverter rating		8,000	W
Inverters required		100	
Cost	$	3,000	
Total cost	**$**	**300,000**	

BATTERY (detailed in Battery Sizing sheet)			
Total energy required		9,378,571	Wh
Amp Hours required for 12 V battery		781,548	Ah
us185hcxc 12 v 220 ah deep cycle batter		220	Ah
Number of battery:		3,552	
Cost	$	293	
Total cost	**$**	**1,039,387**	

DIESEL GENERATOR (direct peak energy sourcing & charging)			
Cummins Lean Burn QSV91 Series Generators	C2000N5C	C2000N5C	
existing gas generator 1250 KVA ~ 1 MW			
Capital cost	₹	16,000,000	
	$	**266,667**	
Fuel cost per hour	$	187	$ per hou
Operation time per day		5	hrs
Total fuel cost	**$**	**937**	$ per day

Not insignificant! Rs. 15/kWh ($ 0.25/kWh)

Capital costs, overall

Solar Panels	$	1,266,666.67	44%
Inverters	$	300,000	10%
Batteries	$	1,039,387	36%
Diesel Generator	$	266,667	9%
	$	**2,872,720.62**	

- If grid, small to no battery costs
- BoS – 30% of solar panel costs (balance of system)
- Could we include wind turbines?
- Fuel costs associated with diesel generator
- Look at the relative percentages – are they correct?
- How to bring down capital costs? *New Topology!*

Interestingly, we found operating costs affect aggregate economics more than capital costs

Revenue generated by the system

Month	Amount in Rs.	Number of units	
Nov-13	₹ 1,430,228.00	237,840	
Dec-13	₹ 1,572,276.00	257,688	
Jan-14	₹ 1,558,503.00	247,632	
Feb-14	₹ 1,563,211.00	256,512	
Mar-14	₹ 1,516,386.00	242,328	
Apr-14	₹ 1,652,188.00	282,204	
May-14	₹ 1,297,116.00	198,384	
Jun-14	₹ 892,508.00	132,408	
Jul-14	₹ 1,069,692.00	176,292	
Aug-14	₹ 1,328,842.00	215,952	
Sep-14	₹ 1,641,477.00	229,212	
Oct-14	₹ 1,851,337.00	265,452	Total Revenue per Year
		3,153,190	₹ 44,144,654.40
			$ 735,744.24

Bill to the Electricity Board is revenue for the microgrid

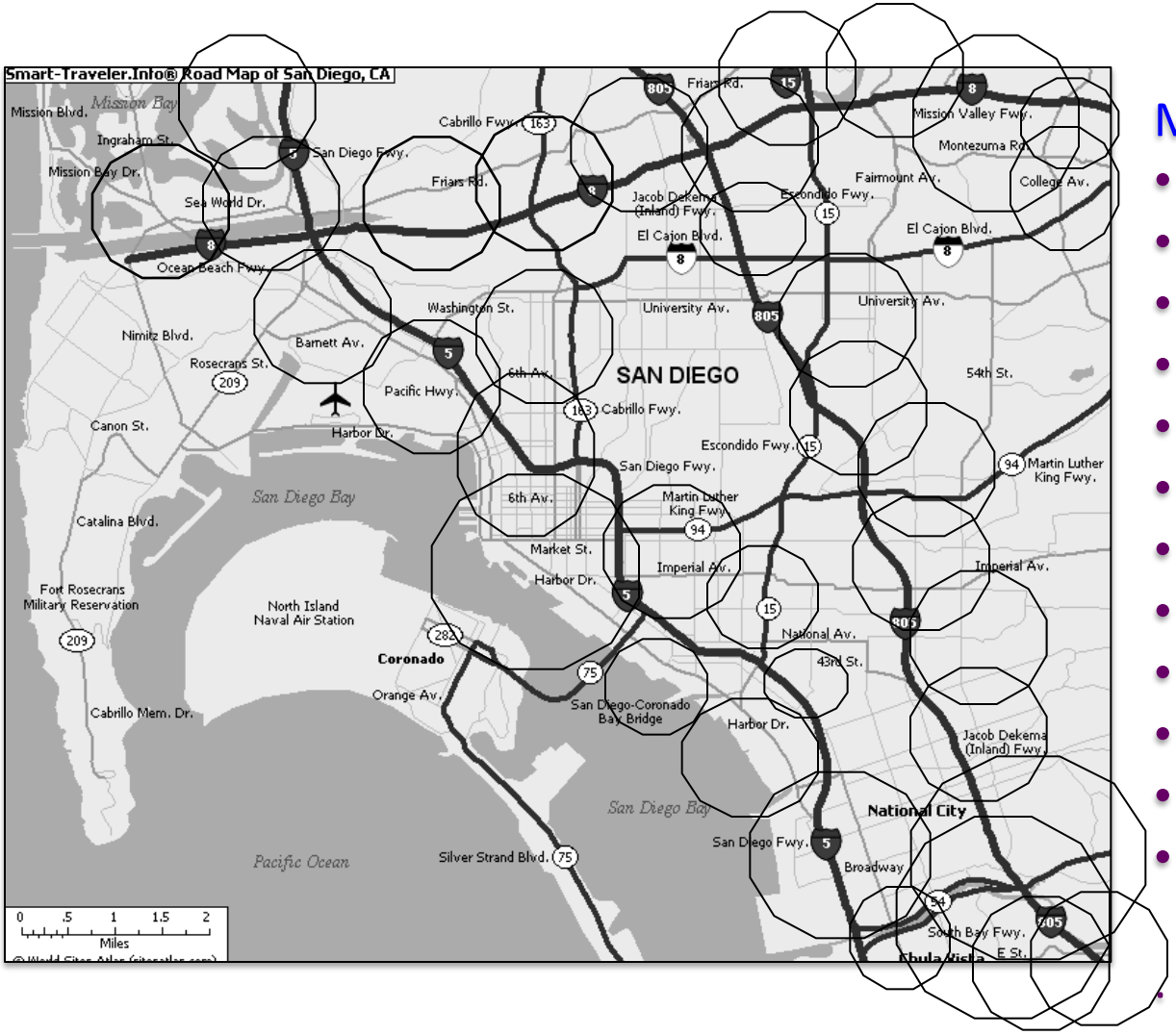
Positive NPV, 19 years to breakeven!

Cost of Equity 10%	Year	0	1	2	3	4	5
Net Income before tax			$ -49,003	$ -27,842	$ 440	$ 24,104	$ 49,637
Depreciation & Amortization			$ 217,583	$ 217,583	$ 217,583	$ 217,583	$ 217,583
Debt Repayment			$ 102,273	$ 193,182	$ 257,576	$ 286,195	$ 278,245
Changes in Working Capital			$ -	$ -	$ -	$ -	$ -
Capital Expenditure (Gross)		$ 3,252,721					$ -
Cash Flow		$ -3,252,721	$ 270,853	$ 382,923	$ 475,598	$ 527,882	$ 545,466
Discounted Cash Flow		$ -3,252,721	$ 248,979	$ 323,134	$ 367,543	$ 372,336	$ 349,761
		$ 59,869	Break even year	**19**			
Total Discounted Cash Flow (Net Present Value)		**$ 428,986**					
Debt/Value ratio			0.50	0.49	0.46	0.41	0.35
Cost of Debt			7.50%	7.50%	7.50%	7.50%	7.50%

$ 0.18/kWh – too much? Not in CA

	Year		1		2		3		4		5
	Revenue	$	735,744	$	757,817	$	780,551	$	803,968	$	828,087
Costs:											
Solar Costs + Balance of System	Depreciation	$	65,867	$	65,867	$	65,867	$	65,867	$	65,867
Inverter Costs	Depreciation	$	30,000	$	30,000	$	30,000	$	30,000	$	30,000
Generator Costs	Depreciation	$	17,778	$	17,778	$	17,778	$	17,778	$	17,778
	Fuel cost	$	341,896	$	348,733	$	355,708	$	362,822	$	370,079
Battery Costs	Depreciation	$	103,939	$	103,939	$	103,939	$	103,939	$	103,939
Operating, Maintenance & Other Costs		$	87,200	$	88,944	$	90,723	$	92,537	$	94,388
	Total operating expense	$	429,096	$	437,677	$	446,431	$	455,360	$	464,467
	Total Depreciation	$	217,583	$	217,583	$	217,583	$	217,583	$	217,583
	Total Expenses	$	646,679	$	655,261	$	664,014	$	672,943	$	682,050
	Earnings Before Interest and Tax (EBIT)	$	89,066	$	102,556	$	116,537	$	131,025	$	146,037
Cost of Debt (Kd)	Interest Cost	$	138,068	$	130,398	$	115,909	$	96,591	$	75,126
7.50%	Initial capital requirement	$	3,681,816								
Debt by Value ratio (D/V)	Equity	$	1,840,908	$	1,840,908	$	1,840,908	$	1,840,908	$	1,840,908
0.5	Debt outstanding	$	1,840,908	$	1,738,635	$	1,545,454	$	1,287,878	$	1,001,683
	Debt repayment	$	102,273	$	193,182	$	257,576	$	286,195	$	278,245
Tax rate	Profit Before Tax (PBT)	$	-49,003	$	-27,842	$	628	$	34,434	$	70,910
30%	Taxable PBT	$	-	$	-	$	628	$	34,434	$	70,910
	Tax	$	-	$	-	$	188	$	10,330	$	21,273
Debt Repayment Years	Net income	$	-49,003	$	-27,842	$	440	$	24,104	$	49,637
18											
	Total cost	$	784,747	$	785,658	$	779,923	$	769,534	$	757,176
	Total cost (Rs.) per day	₹	128,999	₹	129,149	₹	128,207	₹	126,499	₹	124,467
	Number of units		11790								
	Cost per unit (in Rs.)	₹	10.94	$	0.18						

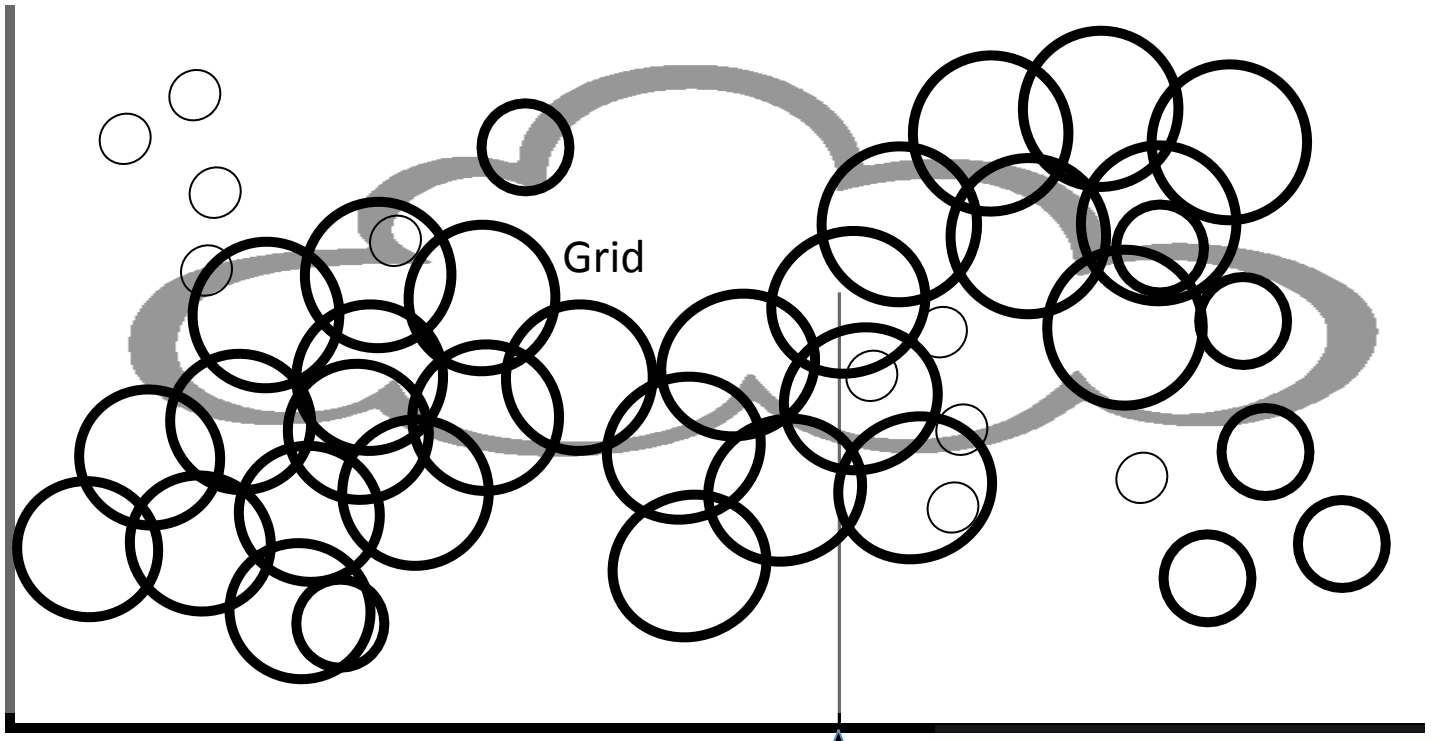
Microgrids – what are these circles?



Microgrid Sites include:

- schools,
- colleges,
- universities,
- hospitals,
- hotels,
- office buildings,
- malls,
- grocery stores,
- office buildings,
- housing societies,
- factories,
- homeowners' association, …

Grid topology evolution



= Solar Home System

= Microgrid

Electricity everywhere

Point of Grid Infeasibility

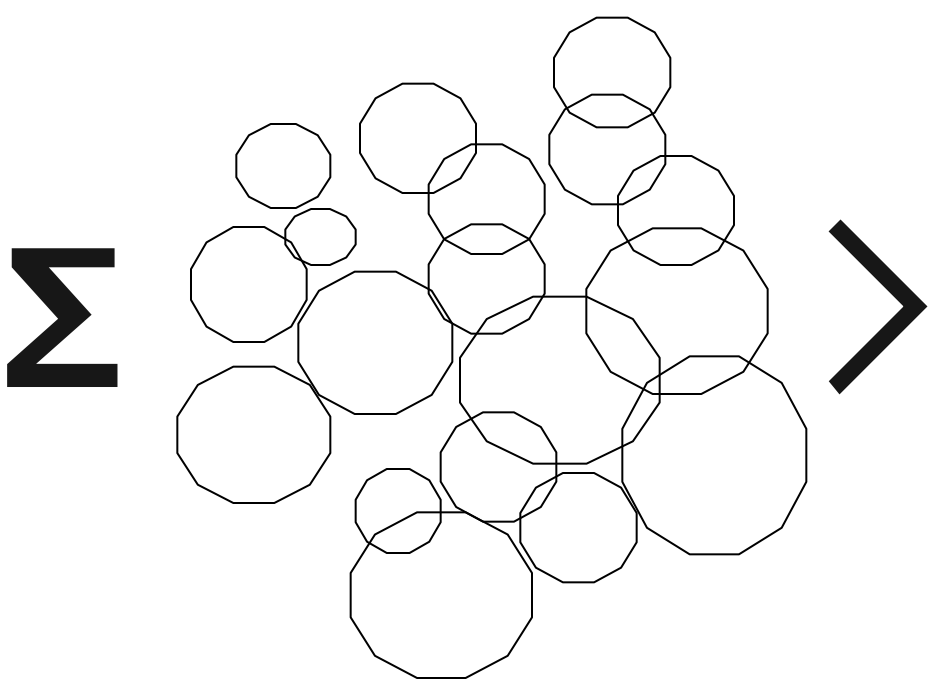
Three levels of players, strategies

- *Entrepreneurial:* strategies deriving from technological advance, New Product or Business
- *Corporate:* Strategies by incumbents, active or defensive, support or impede the new ecosystem
- *Public Policies:* Strategies that create a new ecosystem

Discuss select strategies today

1. ***Miniaturize***
2. ***Fractionate***
3. ***Divest,*** including Municipalize
4. Consolidate
5. a) Privatize b) Public Ownership
6. ***Auction***
7. ***Diversify***
8. Extend geographically with specialization
9. Grow intensively in region
10. Organize differently – cooperatives, franchises, Public-Private-Partnerships …

Miniaturize: Value from microgrids



Traditional macrogrid

Hypothesis: For a given service territory and a set of customers, the sum of the value of microgrids exceeds the value of the corresponding macrogrid"

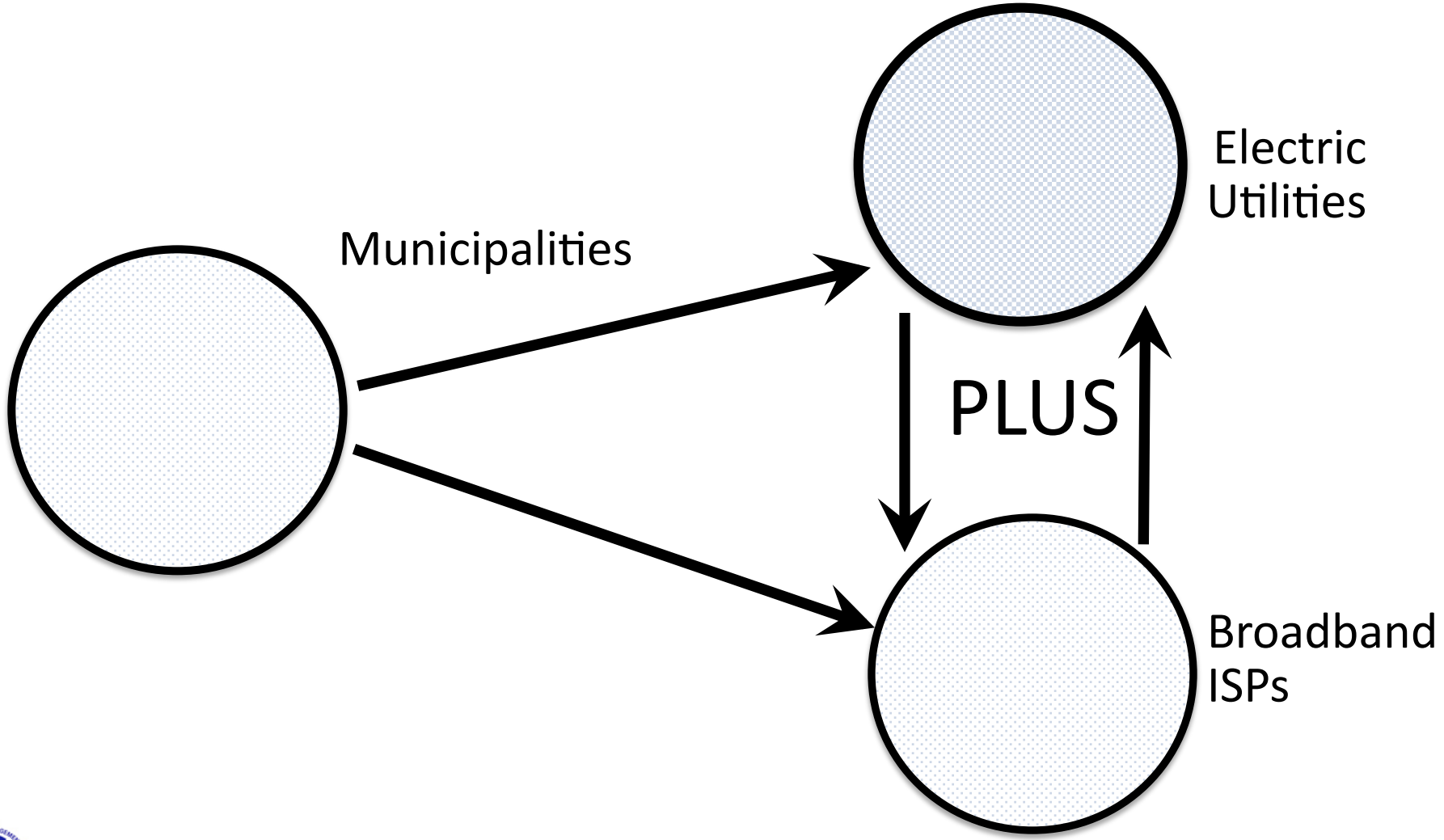
Divest, including Municipalize

- An Investor Owned Utility (IOU) may note
  - fall in demand, due to efficient appliances, the spread of solar systems, …
  - Inevitable drop in market value, and therefore
- *Divest* as strategy: *"if you are falling, dive"*
- Opposite of *municipalization,* though qualitatively similar, where a municipality wrests control of a service territory upon expiration of franchise right
- Municipalization as forced divestiture

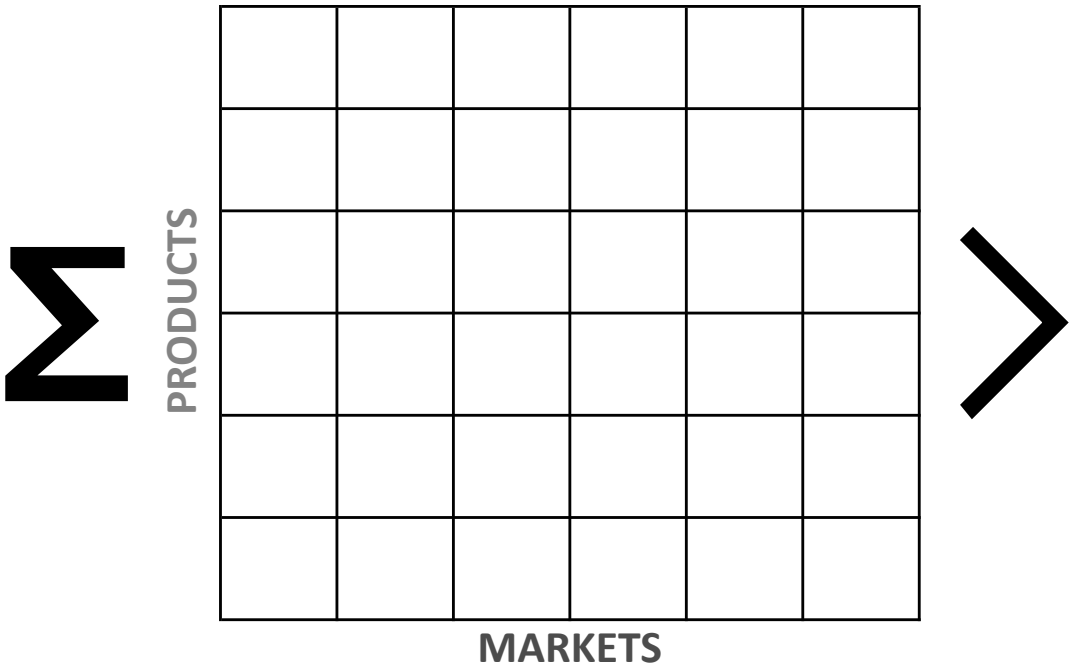
Auction Market Blocks

- Geography may be divided into optimal territories and auctioned off for services
  - Similar to distribution of public, scarce resources, e.g., spectrum by FCC auction
- 2 GHz band auctions in the US in mid-1990s
  - Country divided into 500+ Basic Trading areas; India allocates coal mining rights using auctions
- How to divide geography? By what criteria?

Competition: Municipalities in Electricity, ISP Business



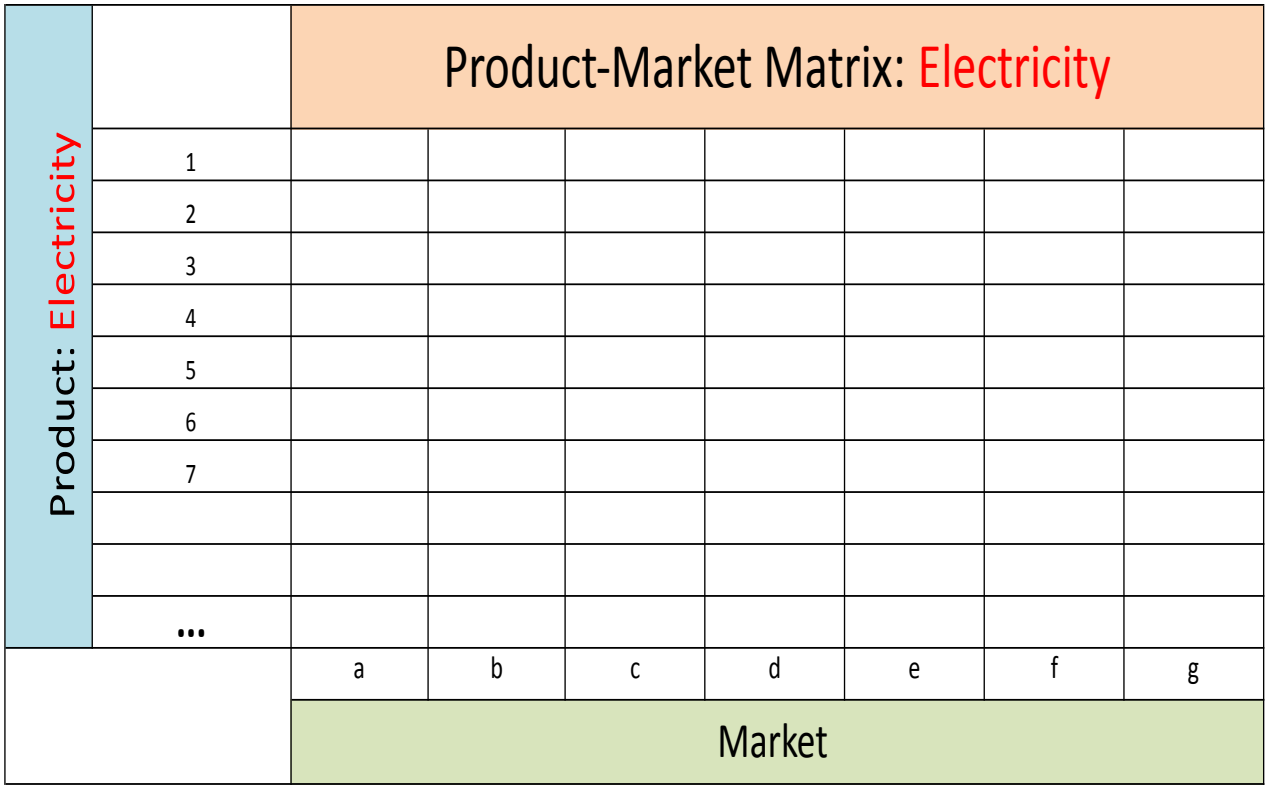
Value from **Fractionation**



Traditional macrogrid

Hypothesis: The sum of the value of "product-markets" exceeds the value of the macrogrid for the same set of customers

Ansoff Matrix: More product, more geography..?



Franchise boundaries less meaningful

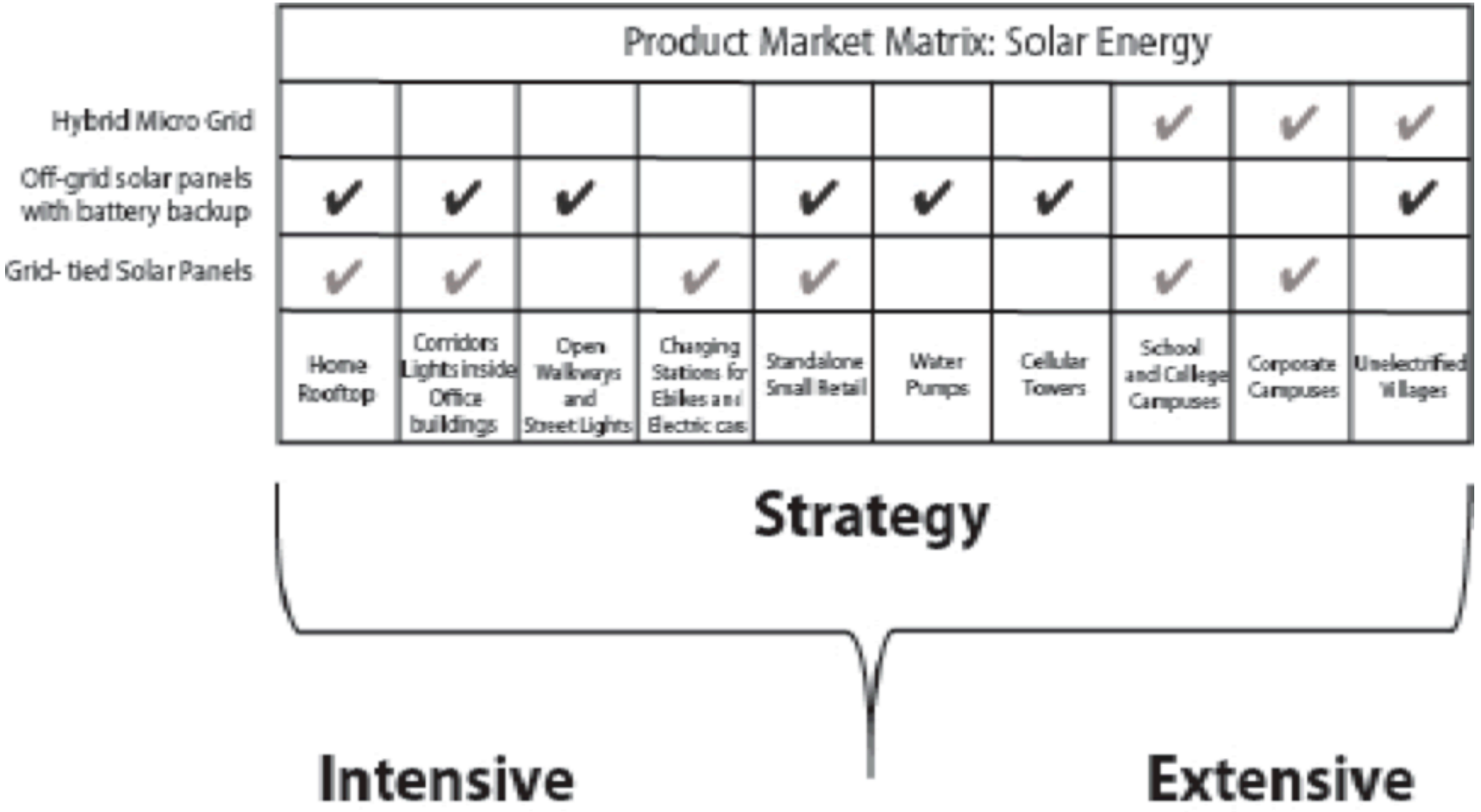
Extend Nationally with Specialization – *Linearly Extensive*

- Seeks scale, therefore lower costs, as also national or global brand
- Through focus and specialization
- For instance, across a nation in solar-powered
  - water pumps for agricultural applications
  - traffic lights
  - street lights on campuses, or city streets

Grow Intensively Within City, Region

- Electrician as utility – solar installation and maintenance business
- A general contractor focused on a city
- Expand portfolio to energy audits, value-added in premise services, LEED certification, DC overlay infrastructure, …
- Expand into facilities management

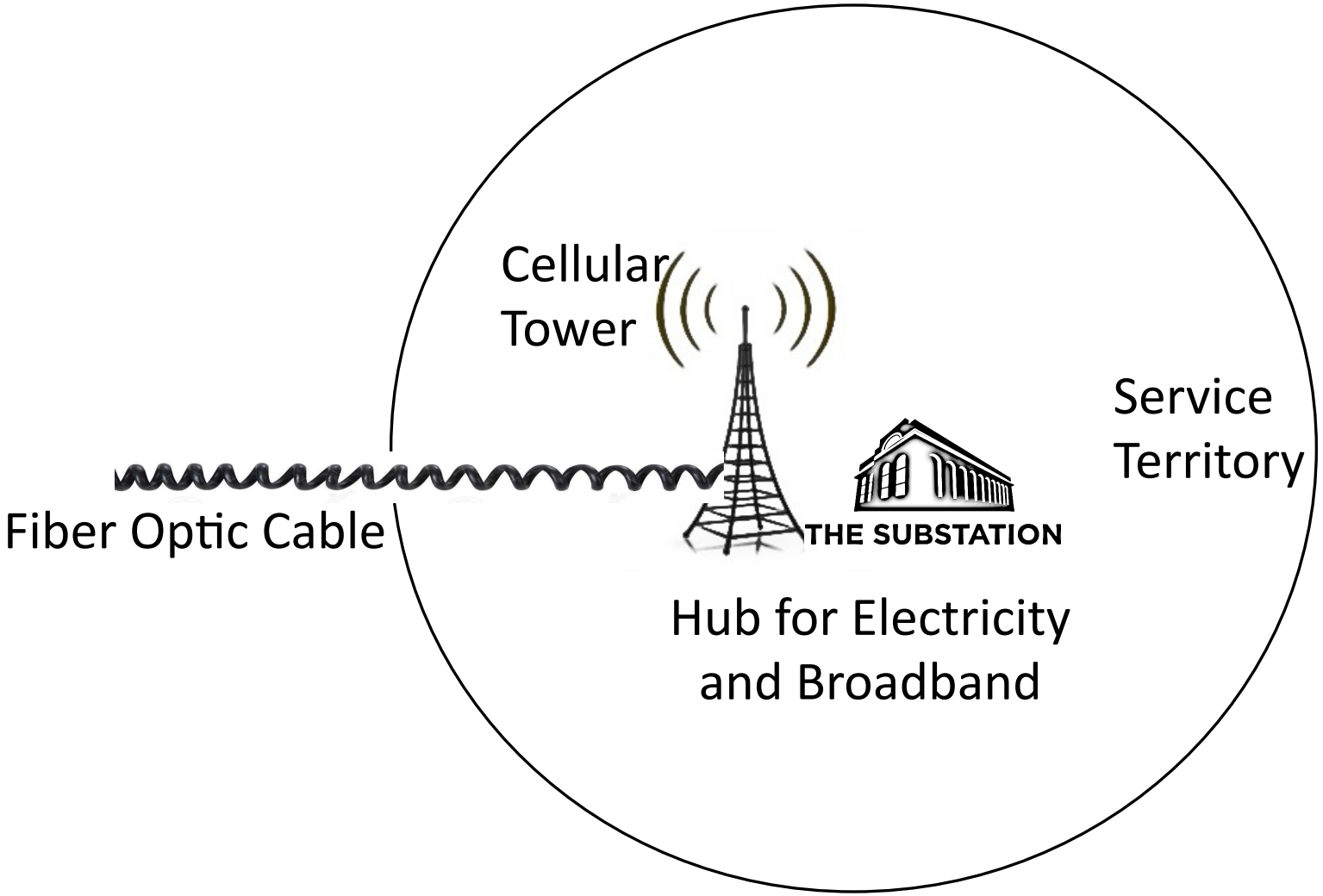
Intensive v. Linearly Extensive opportunities



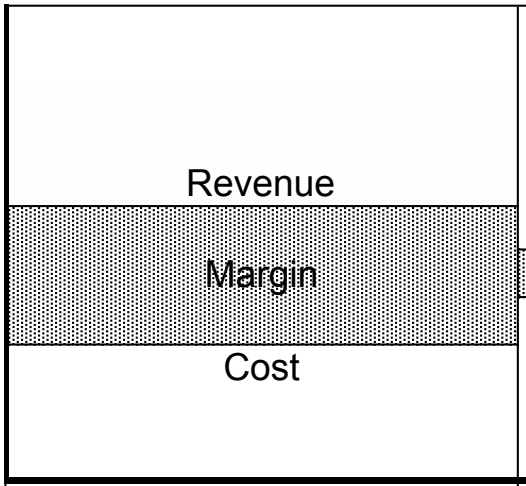
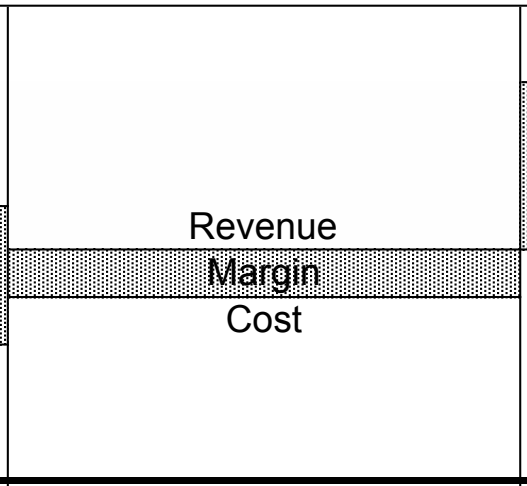
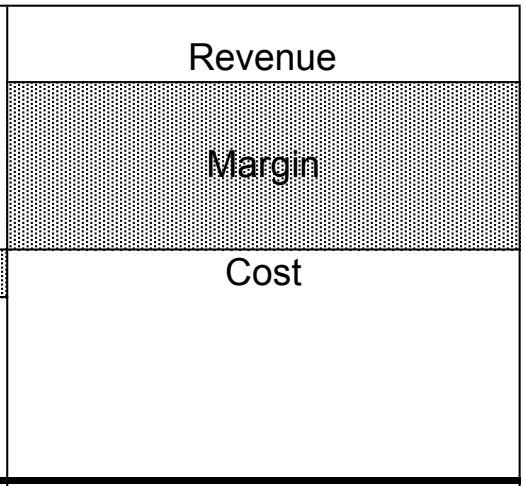
Diversify

- Electric utilities *as ISPs* by leveraging rights of way, customer access, and assets
- New network services
- *As entertainment companies* over Internet
- Like wireline, wireless phone and cable companies
- EPB in Tennessee,

Enter ISP business –
Substation + cellular tower as hub



Increased revenue, margins with broadband

		
Today's regulated business	Regulated with renewables	Electricity plus ISP business
Economies of scale; large scale generation for unit cost reduction. Prices expected to rise due to rising fuel costs, carbon pricing, demand drop, and grid defection	*Economies of numbers; large numbers for unit cost reduction. Somewhat expensive today, costs likely to fall leading to improved margins*	*Economies of numbers + business expansion by leveraging current assets - rights of way, poles, cabling…*
Up to 2020	**2020 through 2030**	**2015 through 2040 and beyond**

Business development, entrepreneurial opportunities, *or competition*

LOCATION

Generate, Use, Buy, Sell	Shopping Mall	✓✓	✓✓	✗	✓✓	✗
Generate, Use, Buy, Sell	Home: Rooftop & Inside	✓	✓	✓	✓	✓
Generate, Use, Buy, Sell	High Rise Office Building	✓✓	✓✓✓	✗	✓	✓
Generate, Use, Buy, Sell	School Yard & Parking Lot; Inside	✓✓	✓	✗	✓✓	✓
Generate, Use, Buy, Sell	High Rise Residential Building	✓	✓✓✓	✓✓✓	✓	✓✓✓
Generate, Use, Buy, Sell	College Campus	✓✓	✓✓	✓	✓✓	✓✓
		Lighting	Energy Efficiency	Cooking	Air Conditioning & Heating	Hot Water

MARKET

What holds back Electricity 2.0?

- Not technology
- Not economics
- Not absence of entrepreneurs
- Not resources
- Not demand

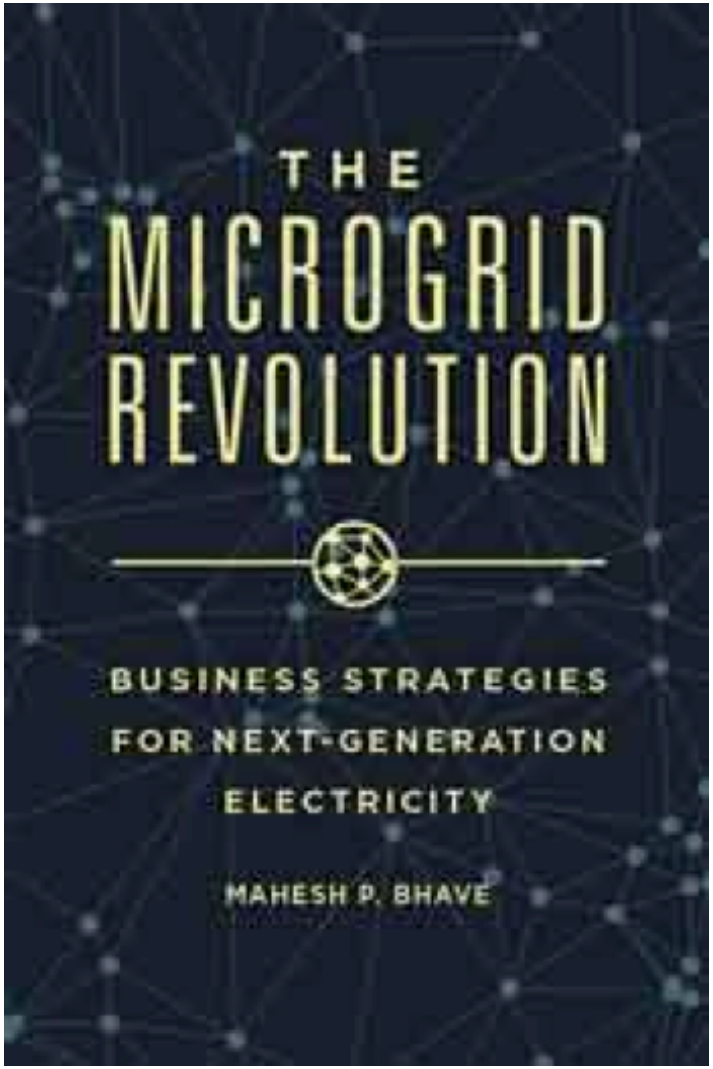
Active Public Policy, and a New Definition of the Public Interest

State-wide: Beyond Municipalities

California ballot initiative would eliminate IOUs, establish statewide public utility – California Electrical Utility District (CEUD)

By Herman K. Trabish | November 3, 2015

http://www.utilitydive.com/news/california-ballot-initiative-would-eliminate-ious-establish-statewide-publ/408452/



Praeger imprint, October 2016

Amazon:
https://www.amazon.com/Microgrid-Revolution-Strategies-Next-Generation-Electricity/dp/144083315X

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