LEVELISED COST OF GREEN HYDROGEN GENERATED FROM VARIOUS RE SOURCES: A STUDY FOR INDIA

¹Jyoti Prasad Rout, ¹Dr. Sapan Thapar, ²Abhinav Jain 1-TERI School of Advanced Studies, New Delhi, India 110070 2-GIZ India, New Delhi, India 110003

INTRODUCTION							OBJE	CTIVE				
Current Study calculates, analyzes and compares the levelized cost of gH2 (LCOH) with energy input from different types of renewable energy sources 1. Solar				- Calculate cost of producing hydrogen through imported Electrolyser and using various RE (Wind, Solar, Hybrid, RTC) sources in India.								
power, 2. Wind and 3. Wind-Solar Hybrid and 4. RIC RE				- A comparison of LCOH across different KE sources to								
(Round The Clock RE). Sensitivity analysis is then				find out the best RE source for green H2 production.								
narformed to find out factors that affect the most to				- Sensitivity Analysis to find out the parameters that affect								
			$I C \cap H$ the meet									
LCOH. It is found that the cost of electricity (tariff) and												
the efficiency of Electrolyser are the major factors that				sea	rch Qu	estions						
affect the levelized cost of green hydrogen. It was				How much does gH2 cost in Rs/kg?								
clearly established that	other fa	actors like lower	Which RE source is better for aH2 production?									
Electrolycor cost and higher CLIE of DE plant will further				M/hat factors are affecting cost of aU22								
Electrolyser cost and highe		E plant will lutther	what factors are anecting cost of griz :									
ower the LCOH.				INPUT DATA								
METHODOLOGY				LCOH Sensitivity Calculations								
LCOH Calculations				Following are factors								
Step-1						lectionys	EI	CO	ntributing	g to LCOF	-	
Per ka cost of generation was cal	lculated for fo	ollowing cost items for			Cost (Rs.) 🔶 Ef	ficiency	(%) Se	nsitivity			
Year 1 to vear 25.		mowing cost iterns for			v							
O&M Expense	Vital Pa	arameters	CU	F (%)								
Capital Expense (Dep)	ital Expense (Dep) RE & Elec		Tariff (Re		(k)/h	LCON	Te	rm Loan I	nt. %			
term loan Interest	Time P	eriod = 25 Years	Tarr		,, KVVII) 			DE (%)				
erm Ioan Principal Loan Interest = 9%												
working capital Interest	Loan Pe	eriod = 13 Years	R	E 20	ources		FINa	ance				
working capital principal	ROE =	10%			Solar	Wi	nd	Hybrid	Hybric	l Hyk	orid	
ROE	Discou	nt Factor = 10%						(80:20)	(50:50) RTC	(SECI)	
Electricity Cost	RE Sou	rce = RTC (SECI)	Proj	ect Co	ost INR40	0 lacs INF	R650 lacs	INR480 lac	s INR540) lacs		
Stan-2			CUF	1	19%	399	%	23%	30%	80%)	
The levelized cost (Rs/ka) was ca	lculated for e	ach cost item hy	Peri	od	25 vrs	. 25	vrs.	25 vrs.	25 vrs.	25 v	rs.	
IC = SLIM Product of cost of apr	noration	ach cost item by	D:F		70.30	70.	30	70.30	70.30	70.3	0	
SLIM of DE woightage for c	ach year			•	13 yrs	13	Vrc	13 yrs	13 yrs	13.	rc	
Solvi of DF weightage for each year			Luat		0.00/	. 13	915. 0/	0.00/	0.00/		15.	
The sum of all the levelized cost i	itams will pro	vide the total cost of	Inte	rest	9.0%	9.0	70	9.0%	9.0%	9.07	0	
ands or I COH in Rs /ka	items wii pio	vide the total cost of	ROE		10%	105	%	10%	10%	10%		
			LCO	E/ Tai	riff 2.2 Rs.	/kWh 3.4	Rs/kWh	2.49 Rs/kV	Vh 2.57 Rs	s/kWh 2.9*	Rs/kWh	
		RESULTS &	DIS	CU.	SSION							
LCOH (Rs./kg) compariso	on from Vario	ous RE Sources			Electrolyz	zer Efficiency		LCOH Se	<u>nsitivity A</u>	<u>nalysis –</u>	<u>-or</u>	
400 257.40					50%	55%	60%	<u>65%</u>	70%	75%	80%	
350	325.6		-	300	303	275	252	233	216	202	189	
<u>287</u>		279.41	MM	500		213	202	200	210	202	10,	
₹250		244	hs /	350	310	282	258	239	221	207	194	
<u>200</u>			Lak	400	317	288	264	244	227	211	198	
<u> </u>			Ĕ	450	324	295	270	249	232	216	203	
<u><u> </u></u>			II.	500	331	301	276	255	237	221	207	
50			ost	550	339	308	282	260	242	226	212	
0			G C	600	346	314	288	266	247	230	216	
Soalr Wind	Hybrid	Hybrid Hybrid-RTC	lyz	650	353	321	204	271	252	235	221	
	IIYDIIU					521	224				225	
	(80:20)	(50:50)	ctro	700	360	321	300	277	257	240		
	(80:20) RE Sources	(50:50)	Electro	700 750	360 367	321 327 334	300 304	277 282	257 262	240 245	229	
Electricity Cost Capex tern	(80:20) RE Sources n loan Int	(50:50)	Electro	700 750 800	360 367 374	321 327 334 340	300 304 312	277 282 288	257 262 267	240 245 250	229 234	
Electricity Cost Capex tern O&M Expense RoE	(80:20) RE Sources n loan Int king capital Ir	(50:50)	Electro	700 750 800	360 367 374 RE electr	327 327 334 340 ricity Tariff II	300 304 312 NR /kWh	277 282 288	257 262 267	240 245 250	229 234	
 Electricity Cost Capex tern O&M Expense RoE wor 11% 	(80:20) RE Sources n loan Int king capital Ir	(50:50)	Electro	700 750 800	360 367 374 RE electr	327 334 340 icity Tariff I	300 304 312 NR /kWh	277 282 288	257 262 267	240 245 250	229 234	
 Electricity Cost Capex tern O&M Expense RoE 11% 10% 14% 	(80:20) RE Sources n loan Int king capital Ir	(50:50) nt ^{8%} 12%	Electro	700 750 800	360 367 374 RE electr 2 Rs/kWh	327 327 334 340 icity Tariff I 2.5 Rs/kWh	300 304 312 NR /kWh 3 Rs/kWh	277 282 288 3.5 Rs/kWh	257 262 267 4 Rs/kWh	240 245 250 4.5 Rs/kWh	229 234 5 Rs/kWh	
 Electricity Cost Capex term O&M Expense RoE 11% 16% 14% 17% 	(80:20) RE Sources n loan Int king capital Ir	(50:50)	Electro	700 750 800	360 367 374 RE electr 2 Rs/kWh	321 327 334 340 icity Tariff I 2.5 Rs/kWh	300 304 312 NR /kWh 3 Rs/kWh	277 282 288 3.5 Rs/kWh	257 262 267 4 Rs/kWh	240 245 250 4.5 Rs/kWh	229 234 5 Rs/kWh	
 Electricity Cost Capex Capex tern 0& Expense RoE 10% 10% 14% 10% 14% 10% 16% 17% 16% 16	(80:20) RE Sources n loan Int king capital Ir	(50:50) nt ^{8%} ^{12%-} ^{15%-} ^{1%} ^{14%} ^{77%}	Electro	700 750 800 300	360 367 374 RE electr 2 Rs/kWh 158	321 327 334 340 icity Tariff I 2.5 Rs/kWh 181	300 304 312 NR /kWh 3 Rs/kWh 204	277 282 288 3.5 Rs/kWh 226	257 262 267 4 Rs/kWh 249	240 245 250 4.5 Rs/kWh	229 234 5 Rs/kWh 294	
 Electricity Cost Capex tern 0&M Expense 10% 10% 16% 16%	(80:20) RE Sources n loan Int king capital Ir	(50:50) 11^{10} $12\%^{-1}$ $15\%^{-1}$ $1\%^{14\%}$ 14% 77% 10^{10} 10%	W	700 750 800 300	360 367 374 RE electr 2 Rs/kWh 158	327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187	294 300 304 312 NR /kWh 3 Rs/kWh 204 209	277 282 288 3.5 Rs/kWh 226	257 262 267 4 Rs/kWh 249	240 245 250 4.5 Rs/kWh 271	229 234 5 Rs/kWh 294	
Electricity Cost Capex term $0&MExpense$ $Re = Solar,$ 11% 10% 10% 14% 10%	(80:20) RE Sources n loan Int cking capital Ir ^{6%} 9% ¹ 10% ⁻ 10% ⁻ 10% ⁻ 10% ⁻ 50% E = Wind, RE = Hy 287 INR/kg LCOH =	(50:50) nt ^{8%} ^{12%} ^{15%} ^{15%} ^{1%} ^{14%} ^{77%} ^{8%} ^{6%} ⁶ ⁶ ⁶ ⁶ ⁶ ⁶ ⁶ ⁶	/MW	700 750 800 300 350	360 367 374 RE electr 2 Rs/kWh 158 164	327 327 334 340 icity Tariff D 2.5 Rs/kWh 181 187	204 300 304 312 NR /kWh 3 Rs/kWh 204 209	277 282 288 3.5 Rs/kWh 226 232	257 262 267 4 Rs/kWh 249 254	240 245 250 4.5 Rs/kWh 271 277	229 234 5 Rs/kWh 294 299	
Electricity Cost Capex term $0&M$ Expense Re 11% 10% 35% 16% 18% 16% 18% 1% 18% 1% $RE = Solar,$ $RE = Hybrid (80:20)$ $LCOH = 326 INR/kg$ RE	(80:20) RE Sources n loan Int king capital Ir % 9% 10% - 10% - 10% - 10% - 50% 10% - 50%	(50:50) nt $\frac{8\%}{12\%^{-1}}$ $\frac{15\%^{-1}}{1\%}$ $\frac{1\%}{14\%}$ $\frac{1\%}{14\%}$ $\frac{1\%}{14\%}$ $\frac{1\%}{14\%}$ $\frac{1\%}{14\%}$ $\frac{1\%}{14\%}$ $\frac{1\%}{14\%}$ $\frac{1\%}{17\%}$ $\frac{1\%}{11\%}$ 1%	khs /MW	700 750 800 300 350 400	360 367 374 RE electr 2 Rs/kWh 158 164 169	321 327 334 340 icity Tariff D 2.5 Rs/kWh 181 187 187	300 304 312 NR /kWh 3 Rs/kWh 204 209 215	277 282 288 3.5 Rs/kWh 226 232 237	257 262 267 4 8s/kWh 249 254 254 260	240 245 250 4.5 Rs/kWh 271 277 282	229 234 5 Rs/kWh 294 299	
 Electricity Cost Capex term O&MExpense Roe wor 11% 10% 16% 19% 19% 19% 19% 19% 19% 16% 16%<!--</td--><td>(80:20) RE Sources n loan Int king capital Ir ^{6%} 9% 10% 10% 10% 10% - 50% 10% 10% 10% 10% 10% 10% 10% 10% 10% 1</td><td>(50:50) nt = 279 INR/kg (50:50) RE = Hybrid (RTC) LCOH = 244 INR/kg</td><td>Lakhs /MW</td><td>700 750 800 300 300 400 450</td><td>360 367 374 RE electro 2 Rs/kWh 158 164 169 175</td><td>321 327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 197</td><td>300 304 312 NR /kWh 3 Rs/kWh 204 209 215 220</td><td>277 282 288 3.5 Rs/kWh 226 232 237 237</td><td>257 262 267 4 249 249 254 260</td><td>240 245 250 4.5 8s/kWh 271 277 282</td><td>229 234 5 8s/kWh 294 299 305 310</td>	(80:20) RE Sources n loan Int king capital Ir ^{6%} 9% 10% 10% 10% 10% - 50% 10% 10% 10% 10% 10% 10% 10% 10% 10% 1	(50:50) nt = 279 INR/kg (50:50) RE = Hybrid (RTC) LCOH = 244 INR/kg	Lakhs /MW	700 750 800 300 300 400 450	360 367 374 RE electro 2 Rs/kWh 158 164 169 175	321 327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 197	300 304 312 NR /kWh 3 Rs/kWh 204 209 215 220	277 282 288 3.5 Rs/kWh 226 232 237 237	257 262 267 4 249 249 254 260	240 245 250 4.5 8s/kWh 271 277 282	229 234 5 8s/kWh 294 299 305 310	
Electricity Cost Capex term O&MExpense RoE WOT 11% 10% 10% 10% 14% 10% 14% 10% 14% 10% 14% 10% 10% 14% 10% 10% 10% 14% 10%	(80:20) RE Sources n loan Int king capital Ir ^{6%} 9% 10%- 1%- 1%- 1%- 10%- 10%- 50% 10%- 10%- 10%- 10%- 10%- 10%- 10%- 10	(50:50) $M_{12\%}^{N}$ $M_{12\%}^{N}$ M_{12	NR Lakhs /MW	700 750 800 300 300 400 450 500	360 367 374 RE electr 2 Rs/kWh 158 164 169 175 180	327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 197 203	300 304 312 NR /kWh 3 Rs/kWh 204 209 215 220 225	277 282 288 3.5 Rs/kWh 226 232 237 237 242	257 262 267 4 267 249 254 254 260 265	240 245 250 4.5 Rs/kWh 271 277 282 282 287	229 234 5 8s/kWh 294 305 310 315	
 Electricity Cost Capex term O&MExpense Rof 11% 16% 19% 19% 19% 19% 19% 16% 16% 16% 17% 16% 16% 17% 16% 16%	(80:20) RE Sources n loan Int king capital Ir ^{6%} 9% 10%- 1%- 10%- 10%- 50% 50% 10%- 10%- 50% 10%- 10%- 10%- 10%- 10%- 10%- 10%- 10	(50:50) nt 8% 12% 15% 1%	in INR Lakhs /MW	700 750 800 300 300 400 450 500	360 367 374 RE electr 2 Rs/kWh 158 164 169 175 180	321 327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 192 197 203	300 304 312 NR /kWh 3 Rs/kWh 209 209 215 220 225	277 282 288 3.5 Rs/kWh 226 232 237 242 248	257 262 267 4 267 249 254 254 260 265 270	240 245 250 4.5 Rs/kWh 271 277 282 282 287 283	229 234 5 Rs/kWh 294 305 310 315	
 Electricity Cost Capex term O&M Expense Rof 11% 10% 10%	(80:20) RE Sources n loan Int king capital In ^{6%} 9% 10% 10% 10% 10% 10% 10% 10% 10% 10% 10	(50:50) nt 8% 12% 15% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 1% 7% RE = Hybrid(RTC) LCOH = 244 INR/kg or oduction of gH2 and H decreases as the	ost in INR Lakhs /MW	700 750 800 300 300 400 450 500	360 367 374 RE electr 2 Rs/kWh 164 164 169 175 180	327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 197 203 208	294 300 304 312 NR /kWh 3 Rs/kWh 209 209 209 215 220 225 221	277 282 288 3.5 Rs/kWh 226 232 237 242 248 248	257 262 267 4 267 249 254 260 260 265 270	240 245 250 4.5 271 271 282 282 282	229 234 5 8s/kWh 294 305 310 315	
 Electricity Cost Capex term O&M Expense Rof 11% 10% 10%	(80:20) RE Sources n loan Int king capital In ^{6%} 9% 10%- 1%- 1%- 10%- 1%- 10%- 1%- 287 INR/kg LCOH= CLUSION 44 Rs/kg with t cost in the p e LCOH. LCO creases.	(50:50) $M_{12\%}^{K}$ $M_{6\%}^{W}$ $M_{6\%}$	er Cost in INR Lakhs /MW	700 750 800 300 300 400 450 500 500	360 367 374 RE electr 2 Rs/kWh 164 164 169 169 175 180 180	327 334 340 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 192 197 203 208 208 214	300 304 312 NR /kWh 3 204 209 215 220 225 225 231 236	277 282 288 3.5 Rs/kWh 226 232 237 242 248 248 248	257 262 267 4 267 249 254 260 260 265 270	240 245 250 4.5 271 271 282 282 282 283	229 234 5 8s/kWh 294 305 310 315 321 326	
 Electricity Cost Capex term O&M Expense RoE 11% 10% 14% 15% 15% 16% 19% 10% 14% 10% 42% 17% 16% 17% 16% 17% 16% 16% 16% 16% 17% 64% RE Hybrid (80:20) RE LCOH = 326 INR/kg RE LCOH LCOH is found to be 2% hybrid (RTC- SECI) Electricity cost is the dominant has a higher share (77%) in the share of electricity in LCOH in the share of electricity in LCOH	(80:20) RE Sources n loan Int king capital Ir ^{6%} 9% 10% 10% 10% 10% 50% E Wind, RE = HA 287 INR/kg LCOH 287 INR/kg LCOH CLUSION 44 Rs/kg with t cost in the p e LCOH. LCO creases. 58 Rs/kg by le	(50:50) f(50:50) f(50:50) f(50:50) f(50:50) f(50:50) f(50:50) f(50:50) f(50:50) f(7	lyzer Cost in INR Lakhs /MW	700 750 800 300 300 400 450 500 600 650	360 367 374 RE electr 2 Rs/kWh 164 164 169 169 175 180 180	327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 197 203 208 219	300 304 312 NR /kWh 3 Rs/kWh 204 209 215 220 215 220 225 231 231	277 282 288 3.5 8s/kWh 226 237 242 248 248 248 259 264	257 262 267 4 267 249 254 260 260 265 270 270	2400 2450 2500 4.5 2501 2711 2711 282 282 282 283 283 293 304 309	229 234 5 8s/kWh 294 305 310 310 312 321 322	
 Electricity Cost Capex term O&M Expense RoE 11% 16% 19% 10% 10%	(80:20) RE Sources n loan Int king capital In ^{6%} 9% 10% 10% 10% 10% 50% E Wind, 287 INR/kg E E HA COH CLUSION 44 Rs/kg with t cost in the p e LCOH. LCO creases. 58 Rs/kg by k	(50:50) n^{t} $(50:50)$ n^{t} $(50:50)$ n^{t} $(50:50)$ $(50:50)$ $RE = Hybrid(RTC)$ $COH = 244 INR/kg$ n RE electricity from n RE electricity from n decreases as the n decreases as the n decreases as the	strolyzer Cost in INR Lakhs /MW	700 750 800 300 300 400 450 500 600 650	360 367 374 RE electr 2 Rs/kWh 164 164 169 169 175 180 180	321 327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 197 203 208 214 219	300 304 312 NR /kWh 3 204 209 209 209 209 215 220 225 231 231 231	277 282 288 3.5 8s/kWh 226 232 232 232 232 232 232 232 232	2577 2622 2677 4 2677 2249 2254 2260 2265 2270 2270 2270	240 245 250 4.5 250 271 271 282 282 287 287 287 287 287 298	229 234 5 8s/kWh 294 299 305 310 310 310 312 321 321	
 Electricity Cost Capex term O&M Expense RoE Wor 11% 10% 14% 10% 14% 16% 15% 16% 15% 16% 16% 15% 16% 16% 15% 16% 16% 15% 16% 16% 15% 16% 16% 16% 16% 16% 16% 16% 16% 16% 16	(80:20) RE Sources n loan Int king capital In ^{6%} 9% 10% 10% 10% 10% 10% 10% 10% 10% 10% 10	(50:50) $f_{12\%}^{N}$ $f_{12\%}^{N}$ $f_{12\%}^{N}$ $f_{12\%}^{N}$ $f_{12\%}^{N}$ $f_{15\%}^{N}$ f_{15	Electrolyzer Cost in INR Lakhs /MW	700 750 800 300 300 350 400 450 500 600 600	360 367 374 RE electr 2 Rs/kWh 164 169 169 169 180 180	327 334 340 icity Tariff IX 2.5 Rs/kWh 181 187 192 197 203 203 208 214 219 224	300 304 312 NR /kWh 3 Rs/kWh 209 209 209 209 215 220 225 220 225 231 231	277 282 288 3.5 Rs/kWh 2226 232 237 232 237 242 248 253 259 264 269	257 262 267 4 267 249 2254 260 265 260 265 270 281 281	240 245 250 4.5 250 271 271 282 282 287 287 287 298 304 304 309	229 234 5 8s/kWh 294 299 305 305 310 310 310 312 321 321 322	



ROE

- LCOH of around 1\$/kg can be achieved with following inputs. Term Loan Int. %

Electrolyser Cost (INR Lakh) 300 Electrolyser Efficiency 90%

8%

10%

RE electricity Tariff (Rs/kWh)

235

258

80%

280

303

325

LCOH (Rs/kg) 82.53

348

213

CUF of RE Plant

800