

Supplementary Information

Novel Low-Carbon Energy Solutions for Powering Emerging Wearables, Smart Textiles, and Medical Devices - A Panoramic Review

Brindha Ramasubramanian^{1,2}, Subramanian Sundarrajan¹, Rayavarapu Prasada Rao¹, M.V. Reddy³, Vijila Chellappan^{2*}, Seeram Ramakrishna^{1*}

^{*1}Center for Nanofibers and Nanotechnology, Department of Mechanical Engineering, National University of Singapore, Singapore 117576, Singapore

^{*2}Institute of Materials Research and Engineering (IMRE), Agency for Science, Technology and Research (A*STAR), #08-03, 2 Fusionopolis Way, Innovis, Singapore, 138634 Singapore

³Nouveau Monde Graphite, 481 Rue Brassard, Saint-Michel-de-Saints, QC J0K 3B0, Canada

Corresponding author: Seeram Ramakrishna (seeram@nus.edu.sg), Vijila Chellappan (c-vijila@imre.a-star.edu.sg)

World Primary Energy Consumption (2020 - 2050) reported by EIA, October 2021

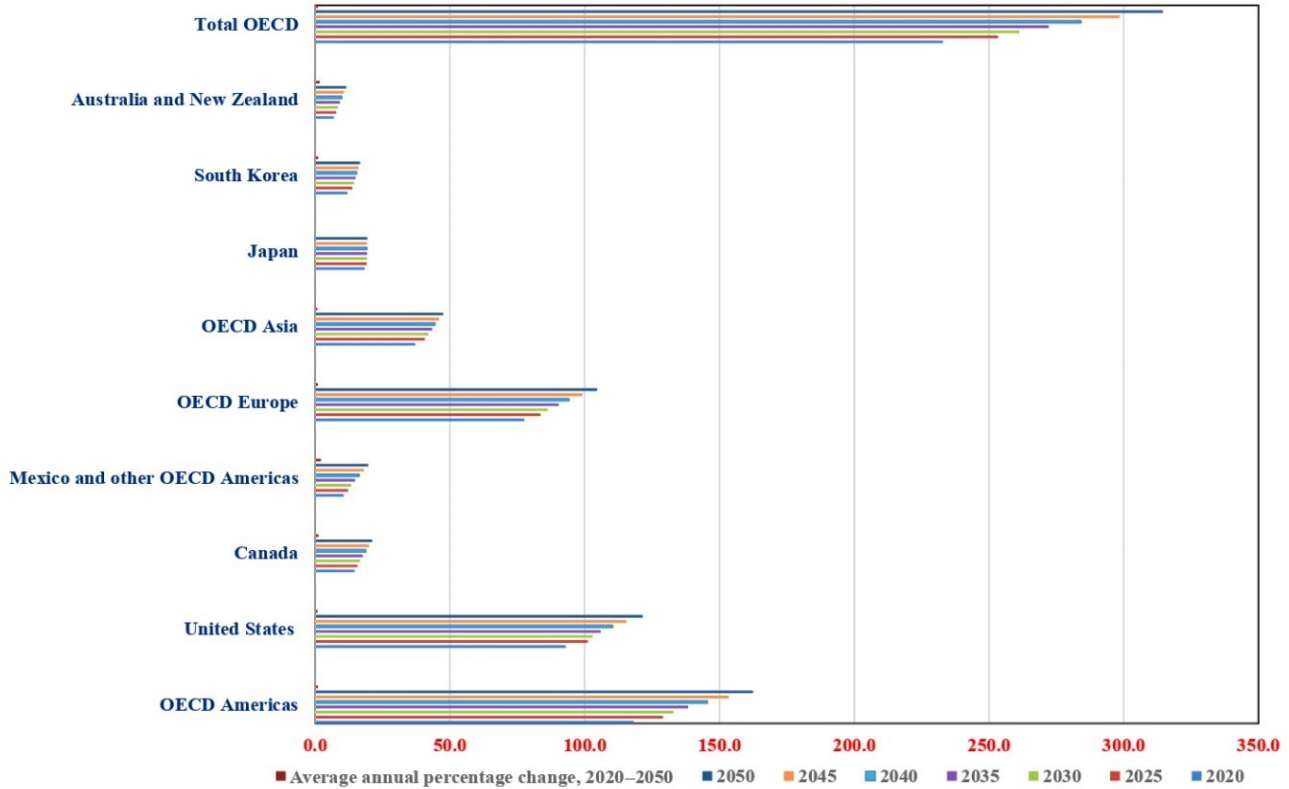


Fig. 1 Global energy consumption (2020 to 2050), reported by EIA, 2021. (Datasets obtained from EIA, Outlook, October, 2021, © EIA).

World Primary Energy Consumption (2020 - 2050), reported by EIA, Non-OECD

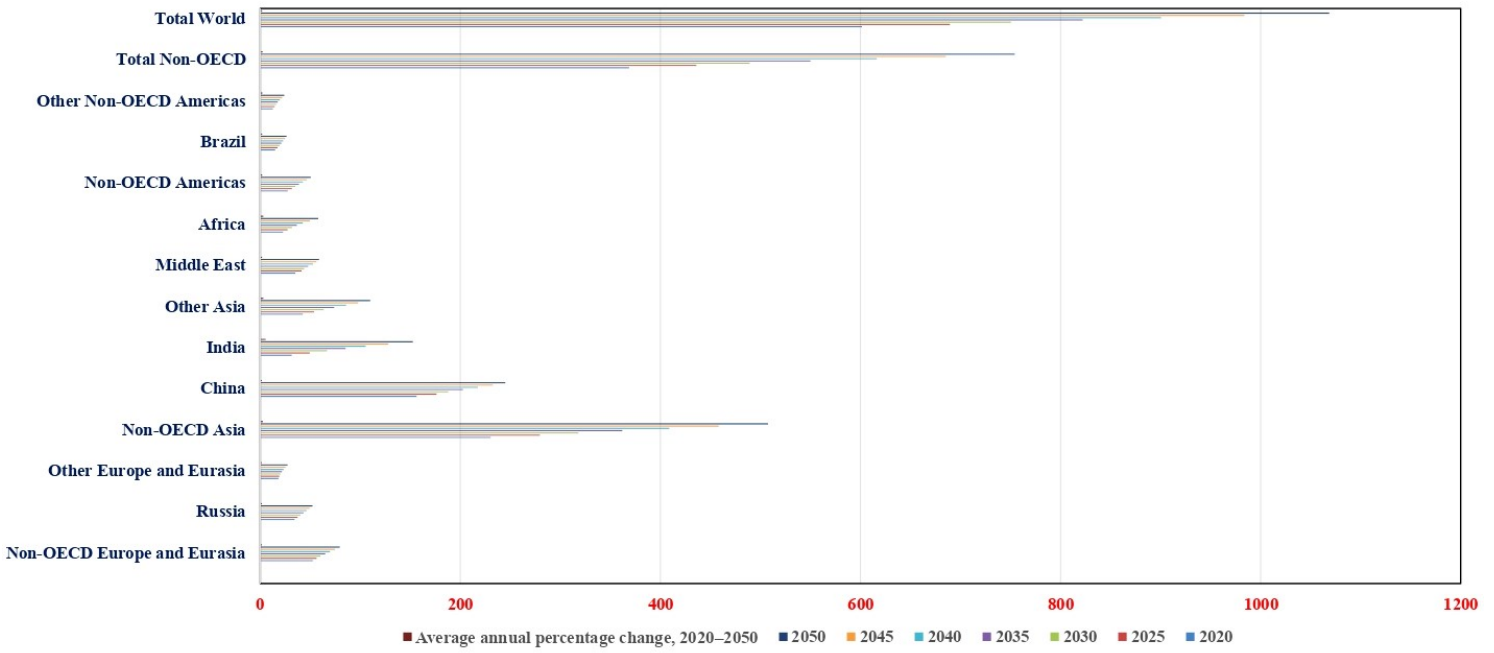


Fig. 2 Energy consumption of non-OECD countries, 2020 – 2050, reported by EIA, 2021. (OECD: Organisation for Economic Co-operation and Development, datasets obtained from EIA, Outlook, 2021, © EIA)

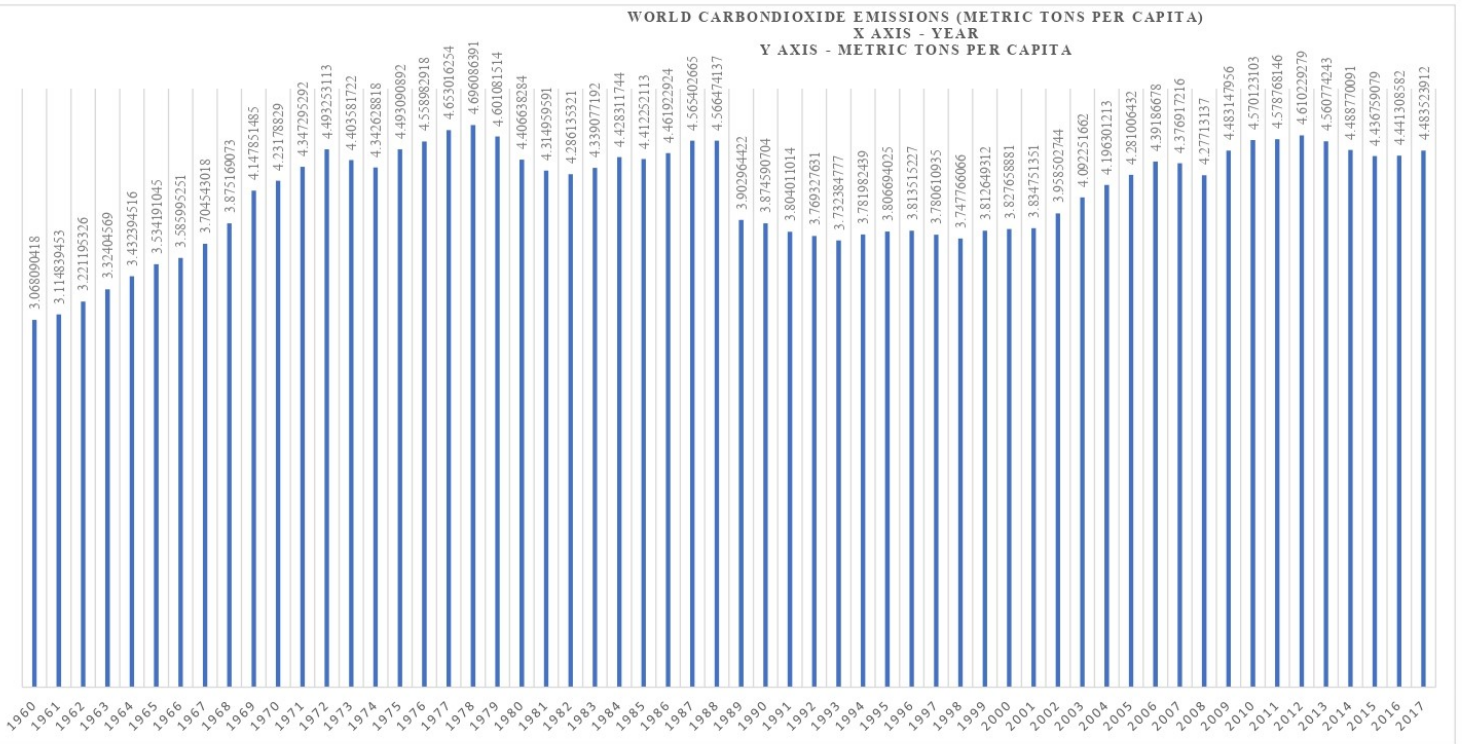


Fig. 3 Global Annual CO2 emission in metric tons per capita, from 1960 to 2017 (datasets obtained from IEA, 2018).



Fig. 4 Zero carbon emission targets for committed countries, according to UN Climate Action Summit, 2019.

Table S1 Recent design structure, Jsc, Voc, FF, PCE of solar cells

Component	Device structure	Jsc (mA cm ⁻²)	Voc (V)	FF	PCE (%)	Ref
Graphene						
Anode	FTO/c-TiO ₂ /MAPbI _{3-x} Cl _x /spiro-OMeTAD/PEDOT:PSS/GR(PDMS/PMMA/GR film)	17.7	0.94	0.72	12	1
Anode	GR/MoO ₃ /PEDOT:PSS/MAPbI ₃ /C ₆₀ /BCP/LiF/Al	21.1	1.03	0.72	16.1	2
Anode	GR/c-TiO ₂ /mp-TiO ₂ /MAPbI _{3-x} Cl _x /spiro-OMeTAD/Au	2.55	0.69	0.35	0.62	3
Anode	PEN/GR/MoO ₃ /PEDOT:PSS/MAPbI ₃ /C ₆₀ /BCP/LiF/Al	21.7	1	0.78	16.8	4
Interfacial layer	FTO/c-TiO ₂ /GRflakes+mp-TiO ₂ /GO-Li/MAPbI ₃ /spiro-OMeTAD/Au		8.57	0.65	12.6	5
EDS layer	N-GQD EDS/FTO/TiO ₂ /γ-CsPbI ₃ /PTAA/Au	19.2	1.11	0.76	16.2	6
ESL	ITO/PEDOT:PSS/MAPbI ₃ /PCBM/GNPs/Al	18.5	0.98	0.78	14.3	7
In ESL	FTO/c-TiO ₂ /mp-GR/SrTiO ₃ /MAPbI ₃ /spiro-MeOTAD/Ag	20	1.03	0.72	14.5	8
In ESL	ITO/SnO ₂ :NDI-GR/FA _{0.75} MA _{0.15} Cs _{0.1} PbI _{2.65} Br _{0.35} /spiro-OMeTAD/Au	22.7	1.08	0.82	20.2	9
Electrode and in ESL	GR/PCBM:GQDs/MAPbI ₃ /PTAA/Au	20.8	1.07	0.74	16.4	10
ESL	FTO/GQD@SnO ₂ /Cs _{0.05} ((FAPbI ₃) _{0.83} (MAPbBr ₃) _{0.17}) _{0.95} /spiro-OMeTAD/Au	23.5	1.08	0.77	19.6	11

ESL	FTO/ZnO/GR/LHP/spiro-OMeTAD/Au	22.7	1.12	0.78	19.8	12
ESL	FTO/c-TiO ₂ :GNRs/mp-TiO ₂ :GNRs/MAPbI ₃ /spiro-OMeTAD/Ag	23	1.05	0.73	17.7	13
Graphene oxide						
In HSL	ITO/PEDOT:PSS:AgOTf-doped GO/MAPbI ₃ - _x Cl _x /PCBM/Au	19.2	0.88	0.71	11.9	14
HSL	ITO/ammonia-treated GO/MAPbI ₃ - _x Cl _x /PC ₆₁ BM/Ag	18.4	1.00	0.77	14.14	15
Interlayer	FTO/c-TiO ₂ /mp-TiO ₂ /GO-Li/MAPbI ₃ /spiro-OMeTAD/Au	19.6	0.86	0.70	11.8	16
In LHP	FTO/spiro-bifluorene/GO-MAPbI ₃ /PC ₆₁ BM/Au	18.8	1.07	0.71	14.3	17
HSL	ITO/GO/MAPbI ₃ - _x Cl _x /PCBM/ZnO/Al	17.5	1	0.71	12.4	18
HSL	ITO/GO/MAPbI ₃ - _x Cl _x /PCBM/BCP/LiF/Al	14.5	0.92	0.72	9.6	19
In LHP	ITO/GO/MAPbI ₃ :GO/PCBM/Ag	20.7	0.93	0.65	15.2	20
Interfacial layer	ITO/PEDOT:PSS-GO:NH ₃ /MAPbI ₃ - _x Cl _x /PC ₆₁ BM/Bphen/Ag	21.7	1.03	0.70	16.1	21
Interfacial layer	FTO/c-TiO ₂ /mp-TiO ₂ /MAPbI ₃ - _x Cl _x /GO/P3HT/Au	24.4	0.93	0.58	13.2	22
Reduced graphene oxide						
Interfacial layer	FTO/c-TiO ₂ /mp-TiO ₂ /FAMACsPbI ₃ - _x Br _x /CuSCN/RGO/Au	23.2	1.11	0.78	20.4	23
In ESL	FTO/c-TiO ₂ /RGO-mp-TiO ₂ nanocomposite/MAPbI ₃ /spiro-OMeTAD/Ag	22	0.93	0.71	14.5	24
In ESL	FTO/ZnO-RGO/MAPbI ₃ /spiro-OMeTAD/Au	21.7	1.03	0.68	15.2	25
In ESL	FTO/c-TiO ₂ /mp-TiO ₂ :RGO(Li treated)/(FAPbI ₃) _{0.85} (MAPbBr ₃) _{0.15} /spiro-OMeTAD/Au	22	1.11	0.80	19.5	26

In ESL,LHP and HSL	FTO/RGO-TiO ₂ /RGO-MAPbI ₃ /RGO-spiro-MeOTAD/Ag	22.9	1.00	0.72	16.5	27
ESL	FTO/c-TiO ₂ :RGO/mp-TiO ₂ :RGO/MAPbI ₃ /spiro-MeOTAD/Au	16.5	0.84	0.68	9.3	28
In LHP	FTO/c-TiO ₂ /mp-TiO ₂ /(FAPbI ₃) _{0.85} (MAPbBr ₃) _{0.15} :N-RGO/spiro-OMeTAD/Au	21.8	1.15	0.74	18.7	29
In LHP	FTO)/SnO _x /((Cs _{0.05} (FA _{0.85} MA _{0.15}) _{0.95} Pb(I _{0.85} Br _{0.15}) ₃ :oxo-RGO/DA/spiro-OMeTAD/Au	23.1	1.13	0.81	21.1	30
HSL and anode	FTO/c-TiO ₂ /mp-TiO ₂ /MAPbI ₃ /RGO	16.7	0.94	0.73	11.5	31
HSL	ITO/RGO/MAPbI ₃ /PC ₆₁ BM/BCP/Ag	14.8	0.95	0.71	10.8	32
Interfacial layer	ITO/c-TiO ₂ /MAPbI ₃ Cl _{3-x} /RGO/spiro-OMeTAD/Au	21.5	1.11	0.78	18.8	33
In HSL	FTO/TiO ₂ /MAPbI ₃ /spiro-OMeTAD/RGO/Au	16.7	0.91	0.006	10.6	34
HSL	ITO/RGO/MAPbI ₃ /PCBM/Ag	21.3	0.96	0.79	16	35
Transparent electrode	RGO/c-TiO ₂ +GR/mp-TiO ₂ +GR/MAPbI ₃ -xCl _x /spiro-OMeTAD/Au	2.9	0.69	0.38	0.81	36
CNT						
	SWCNTs/PEDOT:PSS/MoO ₃ /MAPbI ₃ /C ₆₀ /B CP/Al	19.9	0.98	0.78	15.3	37
	SWCNTs/MoO ₃ /PEDOT:PSS/MAPbI ₃ /C ₆₀ /B CP/Al	17.5	0.96	0.76	12.8	37
Transparent conductive electrode	SWCNTs/PEDOT:PSS/MAPbI ₃ /PCBM/Al	14.9	0.79	0.54	6.3	38
	DWCNTs/PTAA/MA _{0.6} FA _{0.4} PbI _{2.9} Br _{0.1} /C ₆₀ /B CP/Cu	21.4	1.05	0.77	17.2	39
	CNTS-PEDOT:PSS/ZnO/MAPbI ₃ /spiro-OMeTAD/MoO ₃ /Ag	19.4	1.07	0.64	13.3	40
	SWCNTs/PEDOT:PSS/MAPbI ₃ /PCBM/Al	18.3	0.81	0.66	9.8	41

Electron transport layer	FTO/c-TiO ₂ /SWCNTs-m-TiO ₂ /MAPbI ₃ /spiro-OMeTAD/Au	21.4	0.98	0.78	15.3	42
	FTO/c-TiO ₂ /SWCNTs-m-TiO ₂ /MAPbI ₃ /spiro-OMeTAD/Au	21.9	1.04	0.70	16.1	43
	FTO/c-TiO ₂ /SWCNTs-m-TiO ₂ /MAPbI ₃ /spiro-OMeTAD/Au	24.5	1.08	0.73	19.3	44
	FTO/c-TiO ₂ /SWCNTs-m-TiO ₂ /MAPbI ₃ /PTAA/Au	23.6	1.1	0.79	20.4	45
	FTO/c-TiO ₂ /MWCNTs-m-TiO ₂ /MAPbI ₃ /spiro-OMeTAD/Au	27.9	1.08	0.73	21.7	46
	FTO/c-TiO ₂ /MWCNTs-Graphene-m-TiO ₂ /Cs _{0.05} (FA _{0.83} MA _{0.17}) _{0.95} Pb(I _{0.83} Br _{0.17}) ₃ /spiro-OMeTAD/Au	24.8	0.90	0.62	13.9	47
	ITO/CNTs-SnO ₂ /MAPbI ₃ /spiro-OMeTAD/Au	23.2	1.12	0.78	20.3	48
Perovskite layer	ITO/PTAA/MAPbI ₃ /CNTs-PCBM/Ag	23.5	1.04	0.78	19.3	49
	ITO/SnO ₂ /MAPbI ₃ +SWCNTs/spiro-OMeTAD/Au	23.7	1.14	0.72	19.5	50
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ +MWCNTs/spiro-OMeTAD/Au/	20.8	0.97	0.75	15.1	51
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ +MWCNTs/spiro-OMeTAD/Au/	23.6	0.97	0.76	17.4	52
	ITO/PEDOT:PSS/MA _x FA _{1-x} PbI ₃ +MWCNTs/PCBM/Ca/Al	18.2	0.97	0.72	12.9	53
	ITO/SnO ₂ /MAPbI ₃ +s-SWCNTs/spiro-OMeTAD/Au	24.0	1.09	0.79	20.7	54
	FTO/c-TiO ₂ /SnO ₂ /MA _{0.85} FA _{0.15} PbI ₃ +CNTs/spiro-OMeTAD/Ag	23.5	1.09	0.82	21.0	55

	FTO/c-TiO ₂ /SiO ₂ /MAPbI ₃ +MWCNTs/Carbon	21.3	0.92	0.59	11.6	56
	FTO/SnO ₂ /(FA _{0.83} MA _{0.17}) _{0.95} Cs _{0.05} Pb(I _{0.83} Br _{0.17}) ₃ +SWCNTs/spiro-OMeTAD/Au	20.7	1.13	0.69	16.1	57
Hole transport layer	FTO/c-TiO ₂ /Al ₂ O ₃ /MAPbI _x Cl _{3-x} /SWCNTs/PMMA/Ag	17.7	0.97	0.60	10.6	58
	FTO/c-TiO ₂ /Al ₂ O ₃ /MAPbI _x Cl _{3-x} /P3HT/SWCNTs-spiro-OMeTAD/Ag	21.4	1.02	0.71	15.4	59
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /SWCNTs-GO/PMMA/Au	20.1	0.95	0.61	11.7	60
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbBr ₃ /CNTs-PMMA/Au	5.8	1.31	0.75	5.8	61
	FTO/SnO ₂ /FA _{0.83} Cs _{0.17} Pb(I _{0.83} Br _{0.17}) ₃ /SWCNTs-spiro-OMeTAD/Ag	22.4	1.10	0.69	16.8	62
	FTO/SnO ₂ /FA _{0.83} Cs _{0.17} Pb(I _{0.83} Br _{0.17}) ₃ /MWCNTs-spiro-OMeTAD/Ag	22.0	1.07	0.72	17.1	62
	FTO/SnO ₂ /(FA _{0.83} MA _{0.17} Pb(I _{0.83} Br _{0.17}) ₃ /SWCNTs-PMMA/Ag	22.4	1.05	0.74	17.4	63
	FTO/SnO ₂ /(FA _{0.83} MA _{0.17} Pb(I _{0.83} Br _{0.17}) ₃ /SWCNTs-spiro-OMeTAD/Ag	22.1	1.23	0.77	20.9	63
	FTO/c-TiO ₂ /MAPbI ₃ /spiro-OMeTAD/MWCNTs-spiro-OMeTAD/Au	21.6	1.13	0.69	15.1	64
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /CNTs-P3HT/Au	18.7	0.86	0.52	8.3	65
	FTO/c-TiO ₂ /m-TiO ₂ /CsPbI ₂ Br/MWCNTs-P3HT/carbon	13.3	1.21	0.62	10.1	66
	ITO/SWCNTs-PEDOT:PSS/MAPbI ₃ /PCBM/Ag	18.0	0.98	0.71	12.5	67
	ITO/SWCNTs-PEDOT:PSS/MAPbI ₃ /PCBM/Ag	20.3	1.04	0.75	16.0	68

	ITO/s-SWCNTs-NiO _x /MAPbI ₃ /PCBM/Ag	22.0	1.01	0.73	16.9	69
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /SWCNTs-C ₂ uZnSnS ₄ /Au	20.5	1.05	0.70	15.2	70
	FTO/c-TiO ₂ /MAPbI ₃ /SWCNTs-spiro-OMeTAD/Ag	20.8	1.07	0.73	16.1	71
	FTO/c-TiO ₂ /m-TiO ₂ /SWCNTs/MAPbI _x Cl _{3-x} /P3HT/Au	22.8	0.85	0.70	13.6	72
Interlayer	FTO/c-TiO ₂ /MAPbI ₃ /SWCNTs/spiro-OMeTAD/Ag	20.8	1.07	0.73	16.1	71
	FTO/c-TiO ₂ /m-TiO ₂ /CsPbI ₃ /CNTs/Carbon	18.6	0.80	0.71	10.6	73
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /NiO/MWCNTs	22.8	0.91	0.76	15.8	74
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /CuSCN/MWCNTs	23.7	1.10	0.73	17.5	75
	FTO/c-TiO ₂ /m-TiO ₂ /Al ₂ O ₃ /SWCNTs-NiO (MAPbI ₃)	20.7	0.94	0.64	12.7	76
	FTO/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /MWCNTs-P3HT	22.7	0.91	0.65	13.4	77
	FTO/c-TiO ₂ /m-TiO ₂ /Cs _{0.5} (MA _{0.1} FA _{0.83}) _{0.95} Pb(I _{0.83} Br _{0.17}) ₃ /SWCNTs-spiro-OMeTAD	21.0	1.12	0.71	16.6	78
Back electrode	ITO/C ₆₀ /MAPbI ₃ /SWCNTs-P3HT	21.7	0.94	0.67	13.6	79
	ITO/C ₆₀ /MAPbI ₃ /SWCNTs-PTAA	23.0	0.98	0.68	15.3	79
	ITO/C ₆₀ /MAPbI ₃ /SWCNTs-spiro-OMeTAD	23.8	1.08	0.66	17.0	79
	ITO/SnO ₂ /MAPbI ₃ /SWCNTs-MoS ₂ -spiro-MeOTAD	23.8	1.00	0.63	15.0	80
	ITO/SnO ₂ /FA _x Cs _{1-x} PbI ₃ /SWCNTs-spiro-MeOTAD	24.2	1.00	0.72	17.5	81
	ITO/SnO ₂ /MAPbI ₃ /CNTs-spiro-MeOTAD	22.7	1.12	0.73	18.8	82

	ITO/PEDOT:PSS/MAPbI ₃ /PCBM/SWCNTs	18.1	0.79	0.73	11.0	83
	SWCNTs/PEDOT:PSS/MAPbI ₃ /SWCNTs-PCBM	15.9	0.80	0.57	7.3	83
	PET/SWCNTs-MoO ₃ /PEDOT:PSS/MAPbI ₃ /C ₆₀ /BCP/Al	18.8	0.90	0.65	11.0	84
	Ti/TiO ₂ /MAPbI ₃ /CNTs-spiro-OMeTAD	14.3	0.99	0.68	8.3	85
	PET/SWCNTs-P3HT/PEDOT:PSS/MAPbI ₃ /SWCNTs-PCBM	16.0	0.79	0.56	7.1	86
2D flexible PSCs	PET/SWCNTs/PEDOT:PSS/MAPbI ₃ /PCBM/Al	16.4	0.80	0.55	7.2	86
	PEN/ITO/NiO/Al ₂ O ₃ /SnO ₂ @MWCNTs(MAPbI ₃)	19.2	0.91	0.60	10.5	87
	PET/graphene/TiO ₂ /PCBM/MAPbI ₃ /MWCNTs-spiro-OMeTAD	20.2	0.89	0.65	11.9	88
	PET/graphene/TiO ₂ /PCBM/MAPbI ₃ /MWCNTs	18.9	0.82	0.53	8.4	88
1D flexible PSCs	Stainless steel/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /spirom-OmeTAD/CNTs	10.2	0.66	0.48	3.3	89
	Ti/TiO ₂ /MAPbI ₃ /CNTs	14.5	0.87	0.56	7.1	90
	PEN/ITO/c-TiO ₂ /MAPbI ₃ /CNTs	15.9	0.91	0.65	9.4	91
	CNTs/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ /spirom-OmeTAD/CNTs	2.1	0.82	0.35	0.6	91
	CNTs/c-TiO ₂ /m-TiO ₂ /MAPbI ₃ -xCl _x /SWCNTs/CNTs	8.7	0.61	0.56	3.0	92

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