Focus Group Discussion

India TIMES Model (Electricity)- Key Inputs & Results

South Asia Regional Initiative for Energy Integration(SARI/EI)

1 July 2016

Central Electricity Authority, New Delhi

Integrated Research and Action for Development (IRADe)

Contents

- Overview of SARI/EI
- Overview of TIMES Model
- India TIMES Model
- Structure of Energy System (Electricity) considered for Model
- Key Results
- Model Assumptions

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Overview SARI/EI Program: South Asia Regional Initiative for Energy Integration (SARI/EI)

1. SARI/EI is a long standing program of USAID started in the year 2000.

2. Program has consistently strived to address energy security in South Asia by focusing
   1) Cross Border Energy Trade
   2) Energy Market Formation and
   3) Regional Clean Energy Development.

3. SARI/EI–Phase IV (2012-2017): Key Outcomes.
   Three Key Development Outcomes:
   1. Coordinate policy, legal and regulatory issues.
   2. Advance transmission interconnections.
   3. Establish South Asia Regional Electricity Markets.

First Three Year of the Program is Completed.

IRADe- a regional organization, is implementing partner

TIMES MODEL

Key attributes of Times Model

- **Bottom-Up Model Generator**
- **Uses linear-programming to produce least-cost energy system**
- **Optimizes over medium to long-term time horizons**
- **Assumes perfect foresight-** **all investment decisions are made in each period with full knowledge of future events**

In a nutshell, TIMES is used for "the exploration of possible energy futures based on contrasted scenarios"

TIMES objective function: Minimization of total system discounted cost including the useful value of plant at the end of model horizon

Each year, the total cost includes:

- ❑ Capital Costs
- ❑ Fixed and variable annual Operation and Maintenance (O&M) Costs
- ❑ Exogenous imports and domestic resource production costs
- ❑ Exogenous *exports revenues, etc*

India TIMES Model Assumptions and General Settings

- Model Base year 2011-12
- Time horizon: 2012 to 2047 equal time period of 5 years
- The model solves simultaneously for every 5th year- 2012, 2017, 2022, 2027, 2032, 2037, 2042 and 2047
- Discount rate 4% (with 6% inflation this is equivalent to 10%)
- Constant price model at 2011-12 prices
- No Transmission Constraint assumed within the region

Time Sub-Periods/Time-slices and Energy Fraction Generation

- An Year is divided into sub-time periods or Time-slices to capture the fluctuations within a day
- Each time-slice representing one hour of a day for each month i.e. 12 am to 1 am represents first time-slice, 1 am to 2 am represent second time-slice, and so on. Thus every month will have 24 time-slices.
- Total number of time-slices for an year is 288 i.e. 2304 time-slices in the model horizon
- The model balances the demand and supply for each time-slice

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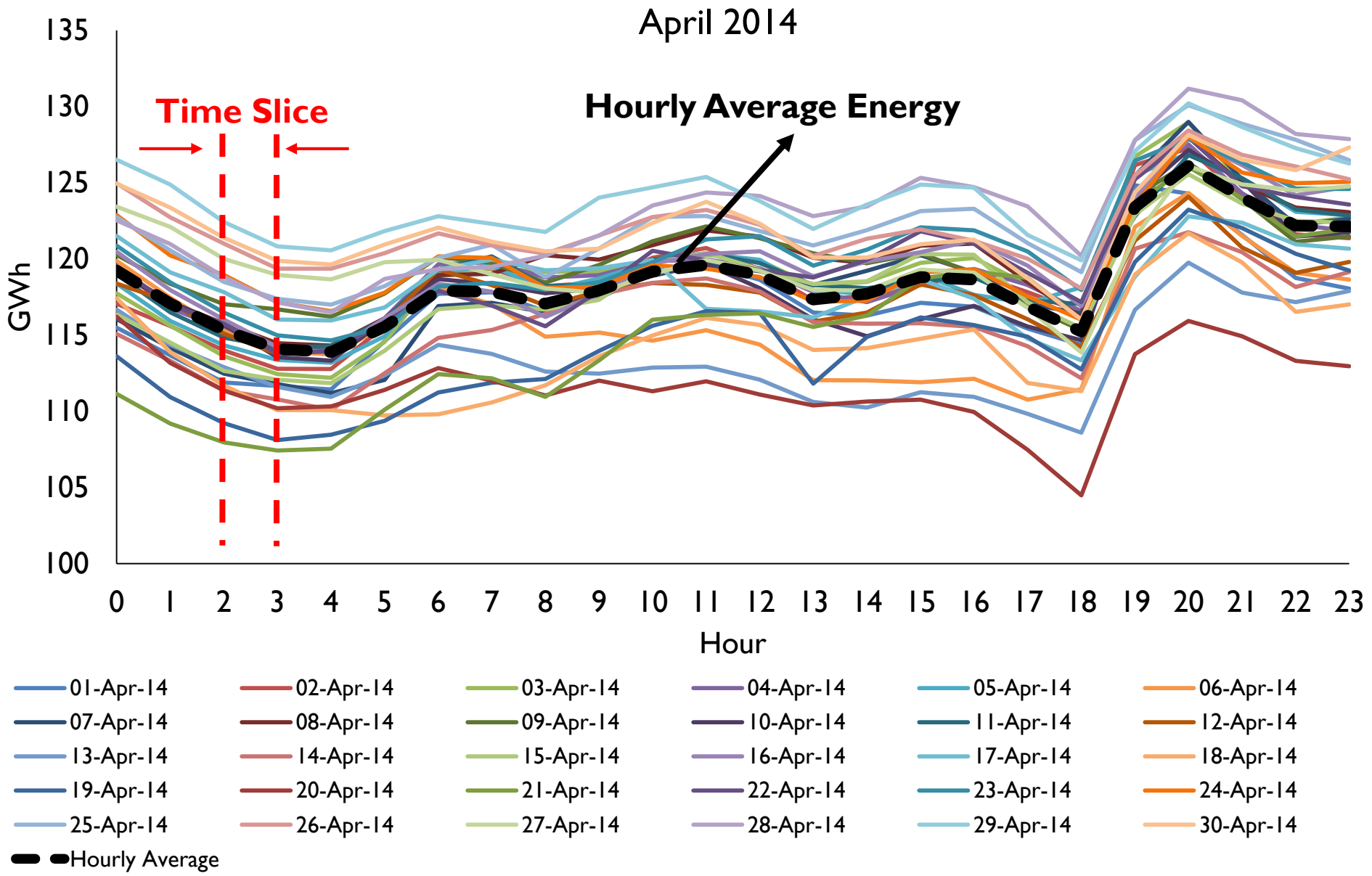
India's Monthly Average Demand for 2014-15



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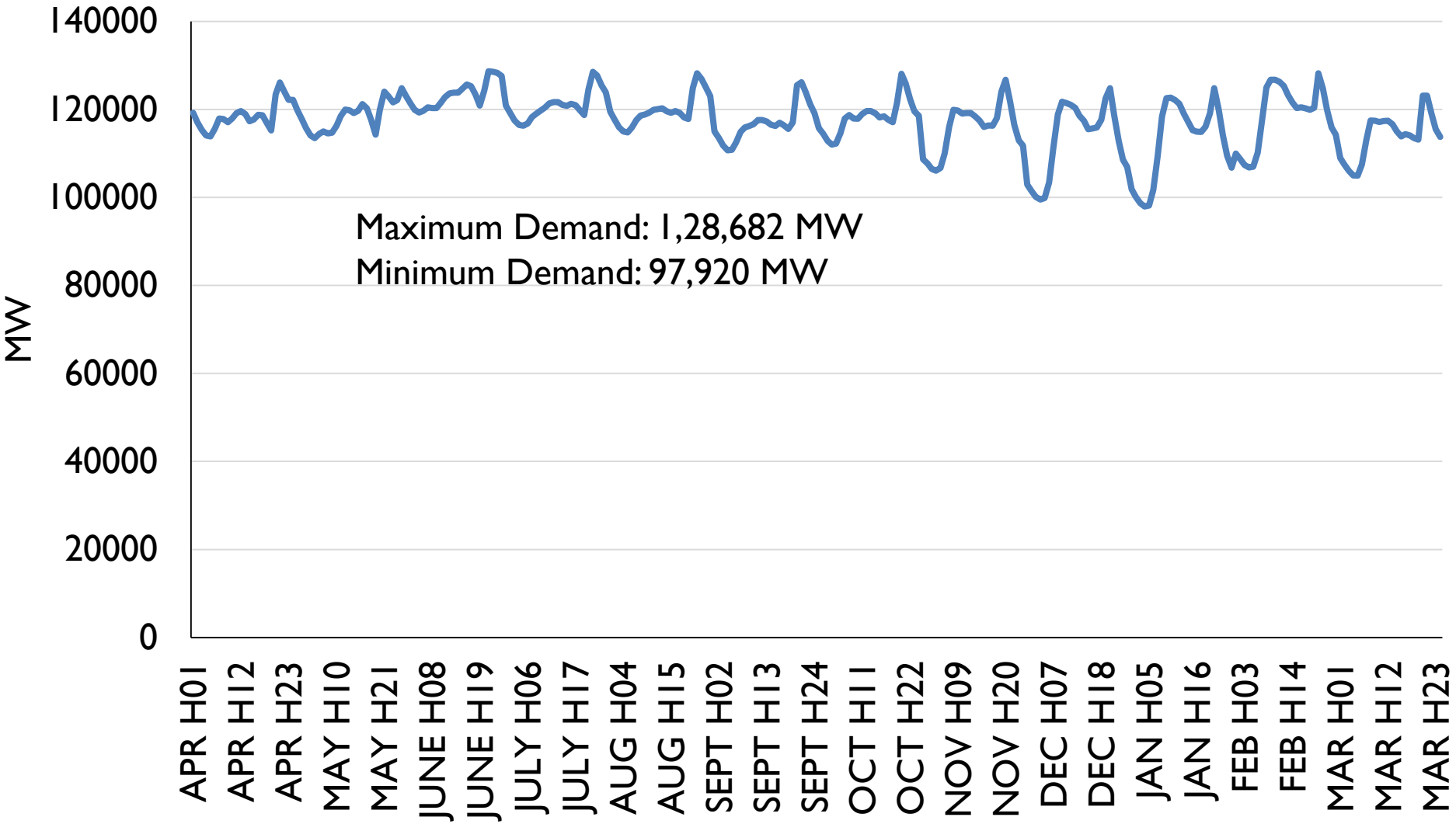
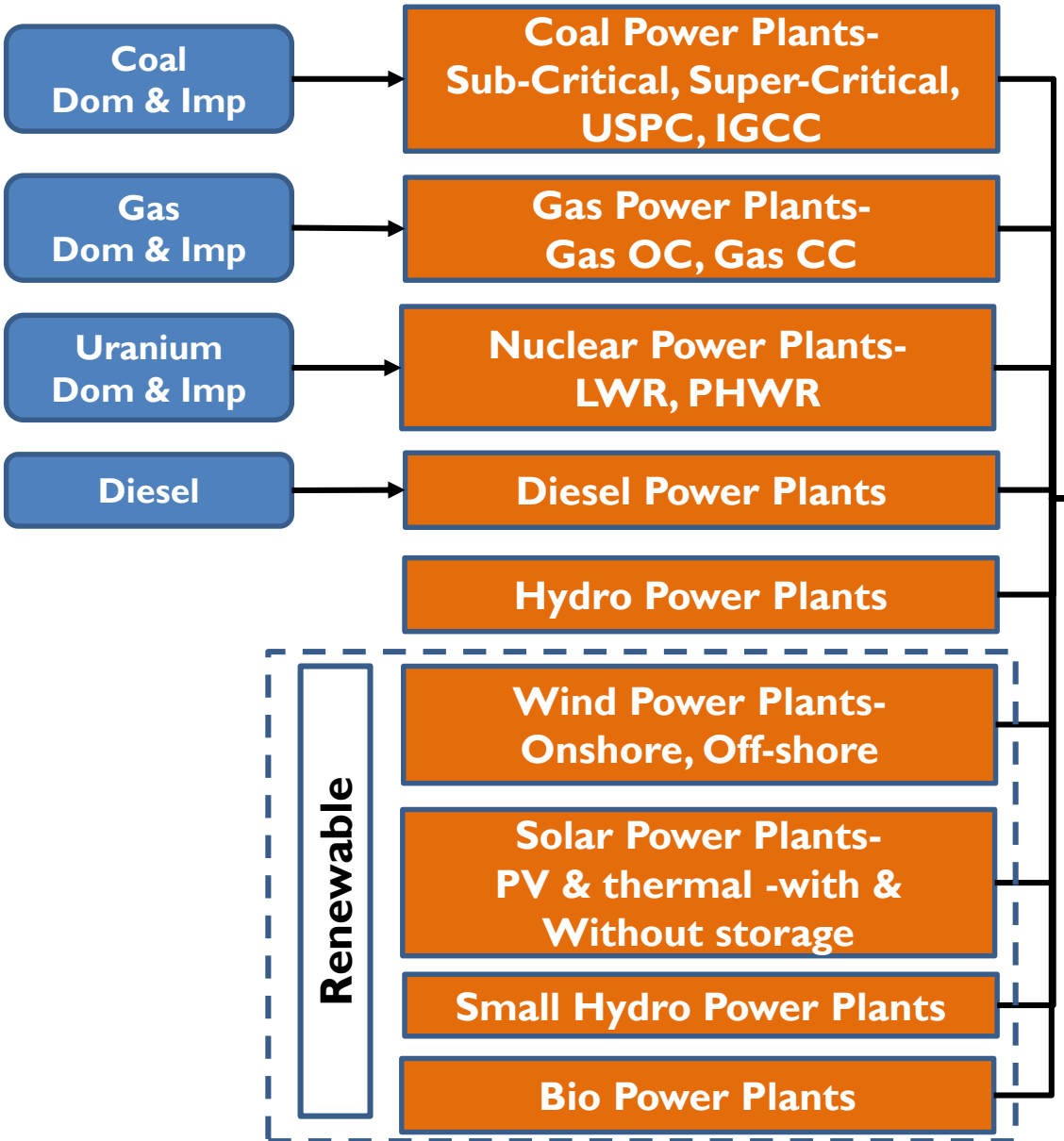


Structure of Energy System (Electricity) Considered For India Model



Key Parameters for Technology Modelling:

- Power plant efficiencies & availability factors
- Costs: Capex, Fixed O&M and Fuel Cost
- Capacity bounds and other user defined alternatives
- Fuels Indigenous availability

Elements of India's Modeling Scenario

- INDC targets as per GoI have been considered viz.
  - Target of 175 GW RE power generation capacity by 2022
  - Minimum 40% Non-fossil fuel capacity by 2030.
- After 2030, Non-fossil fuel capacity assumed to increase by 5% every 5 years to reach 55% by 2047
- Maximum Solar Energy Potential of 748 GW
- Maximum On-shore Wind Potential of 302 GW @ 120 m mast height

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India Model Outputs- No Trade Scenario using demand from IRADe's Macro Model

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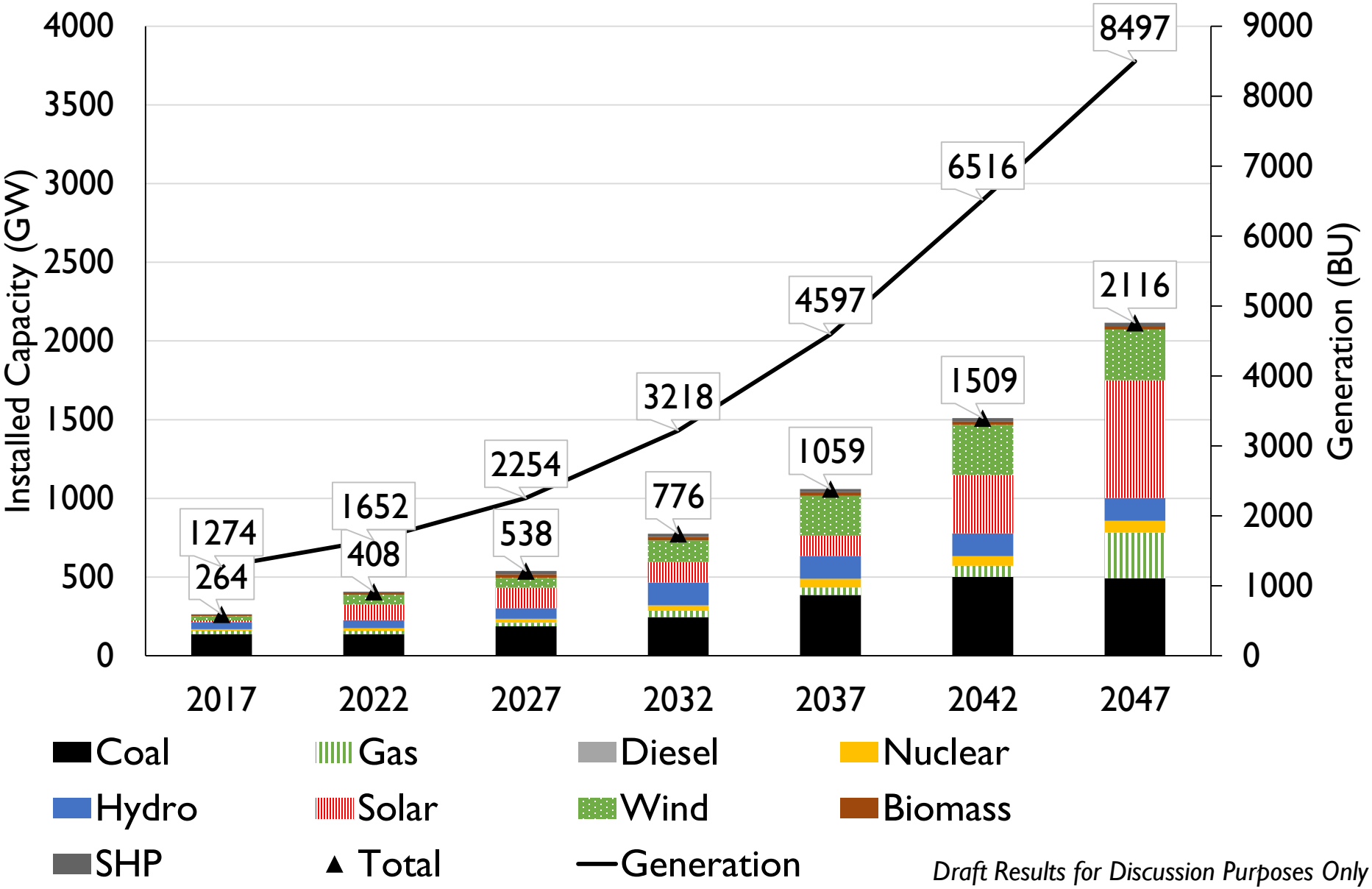
Base Case without Trade for India: Installed Capacity & Electricity generation



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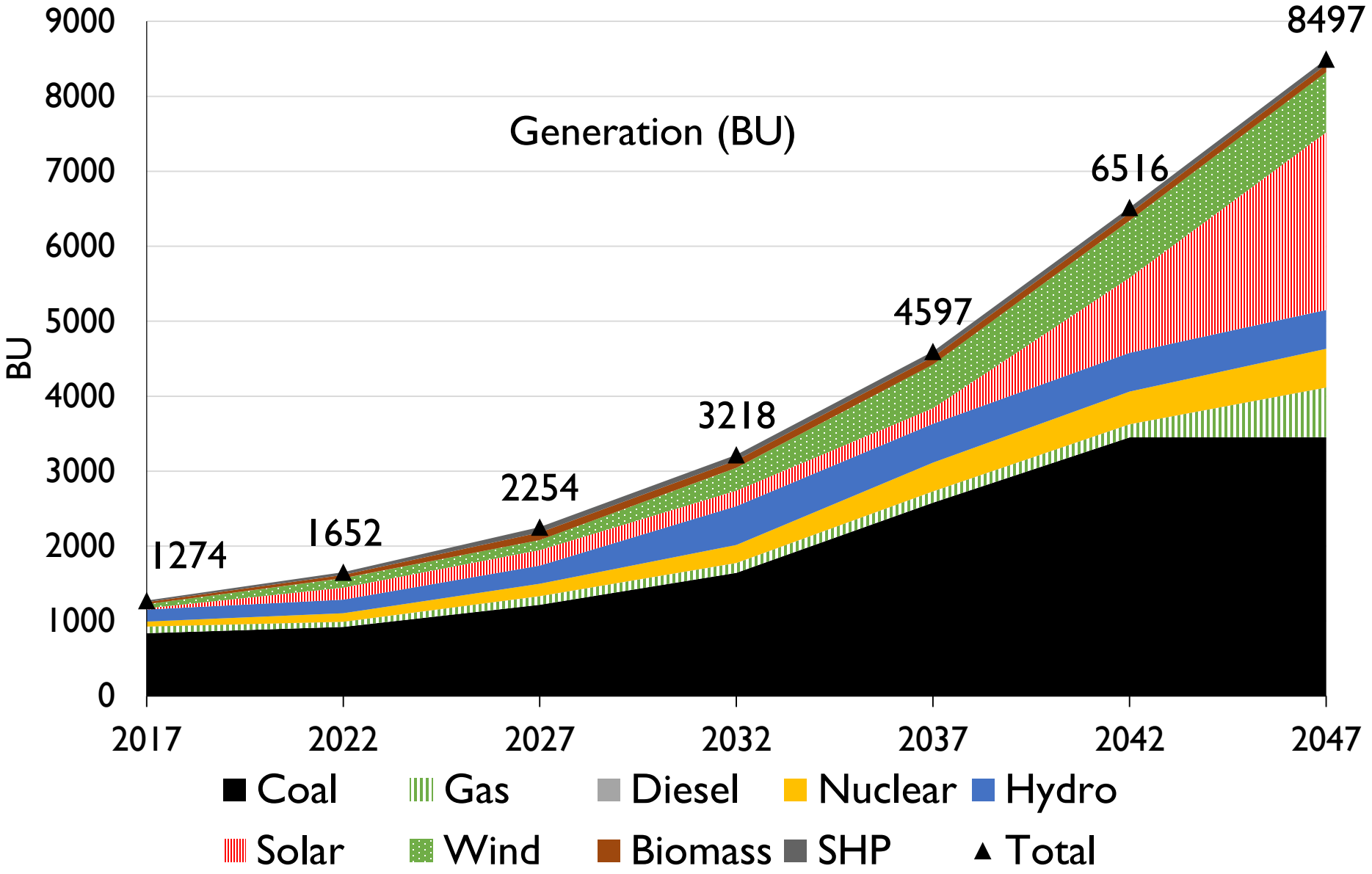
Electricity Generation: India-Without Trade Year Wise (BU)



Share of Fossil and Non-Fossil

% share in Installed Capacity							
	2017	2022	2027	2032	2037	2042	2047
Fossil	60%	39%	39%	37%	41%	38%	37%
Non-fossil	40%	61%	61%	63%	59%	62%	63%
Renewable share	19%	44%	44%	40%	40%	48%	53%

% share in Electricity Generation							
	2017	2022	2027	2032	2037	2042	2047
Fossil	73%	60%	59%	55%	59%	56%	48%
Non-fossil	27%	40%	41%	45%	41%	44%	52%
Renewable share	9%	22%	23%	21%	21%	30%	39%

Average monthly generation & Annual Generation India Model Results-(Without trade)

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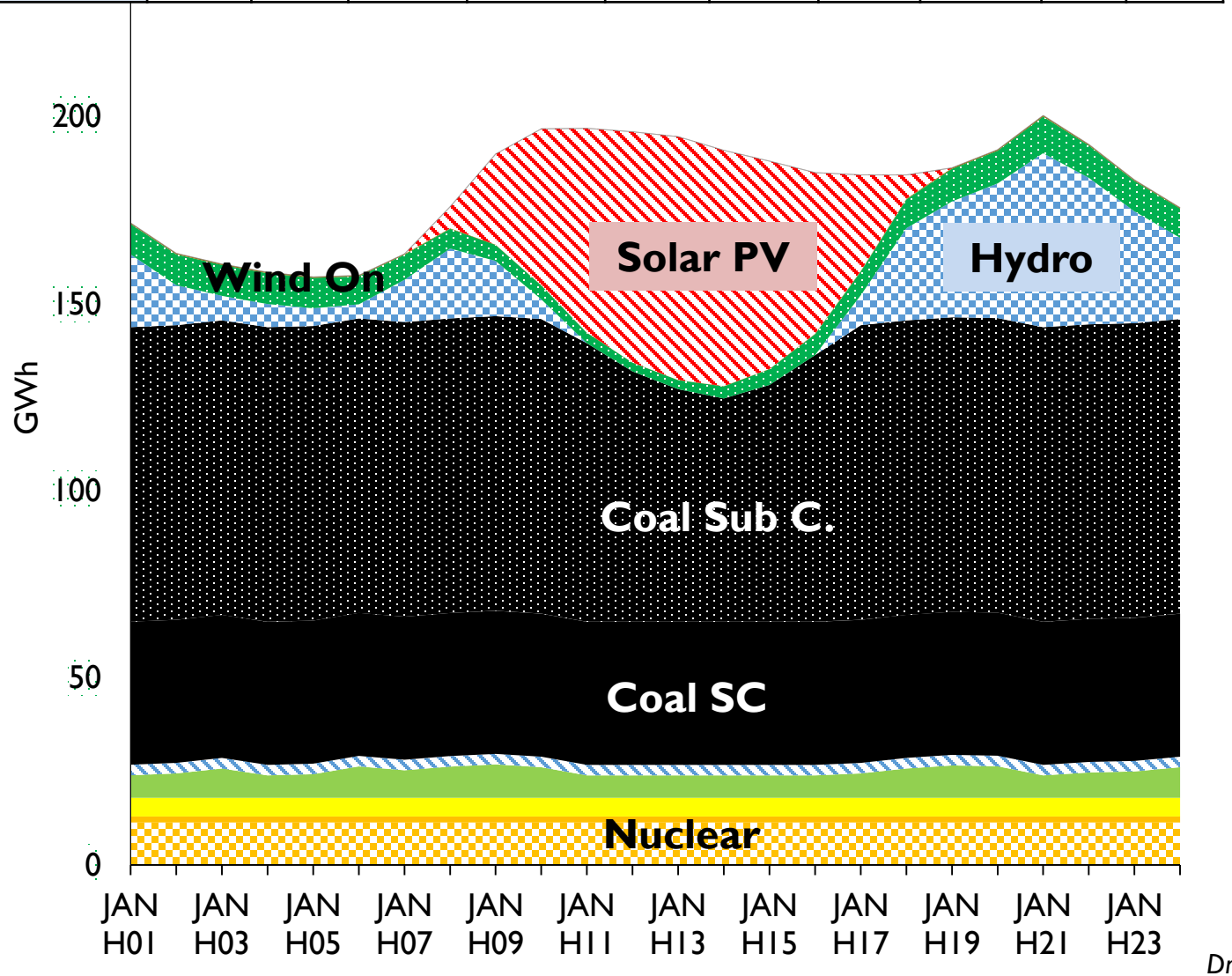
Typical One Day Generation in January 2022 (GWh)

I.C (GW)	Coal	Gas	Diesel	Nuclear	Hydro	Solar	Wind	Biomass	SHP	Total
2022	138	20	1	16	51	100	61	10	10	408



- Diesel
- Gas- Open Cycle
- Solar Thermal With Storage
- Solar Thermal
- Solar PV with Storage
- Solar PV
- Wind Off Shore
- Wind On Shore
- Hydro
- Coal - Subcritical
- Coal- Super Critical
- Coal- Ultra Super Critical
- Small Hydro Power
- Gas- Combine Cycle
- Biopower
- Nuclear-LWR
- Nuclear-PHWR

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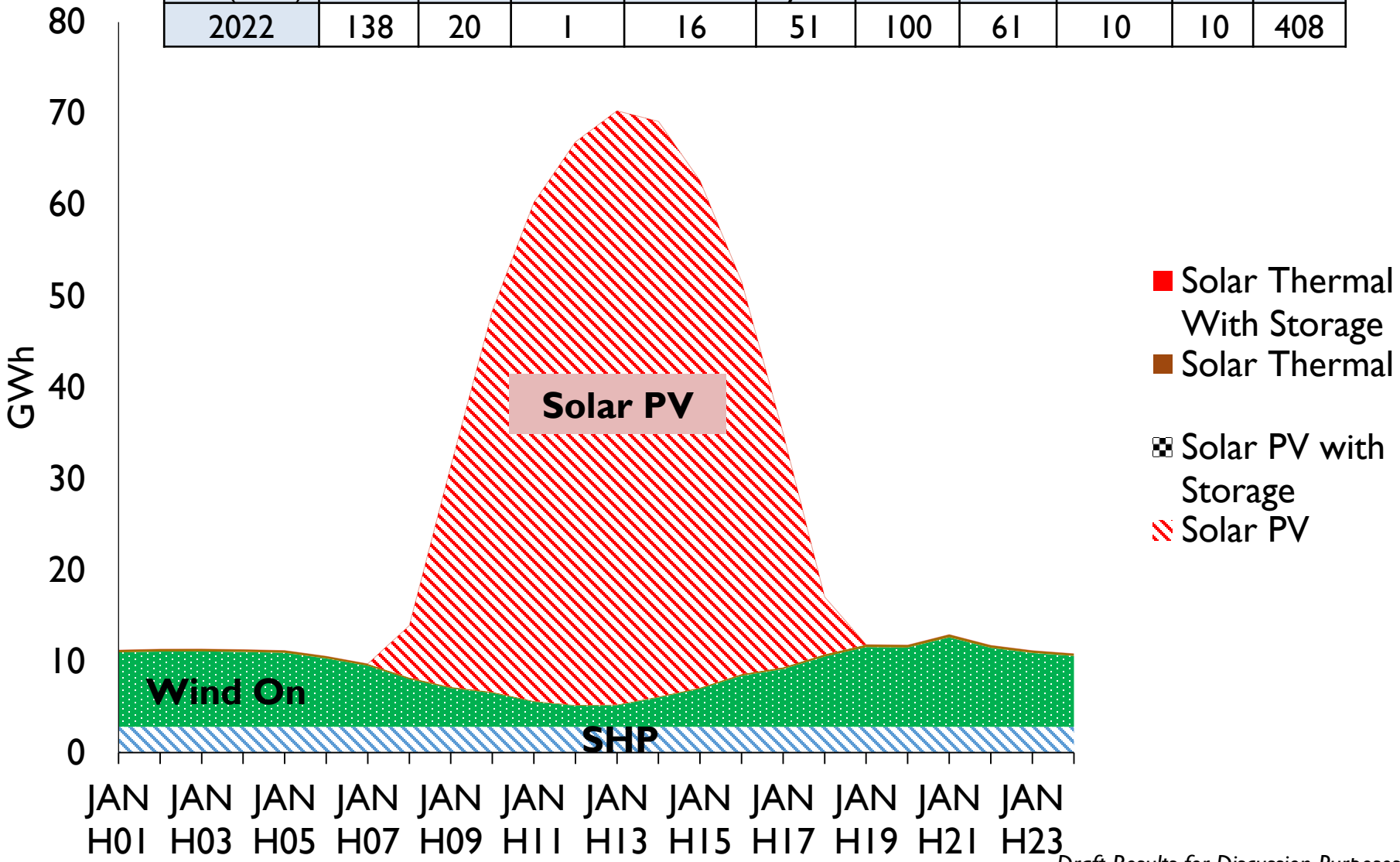

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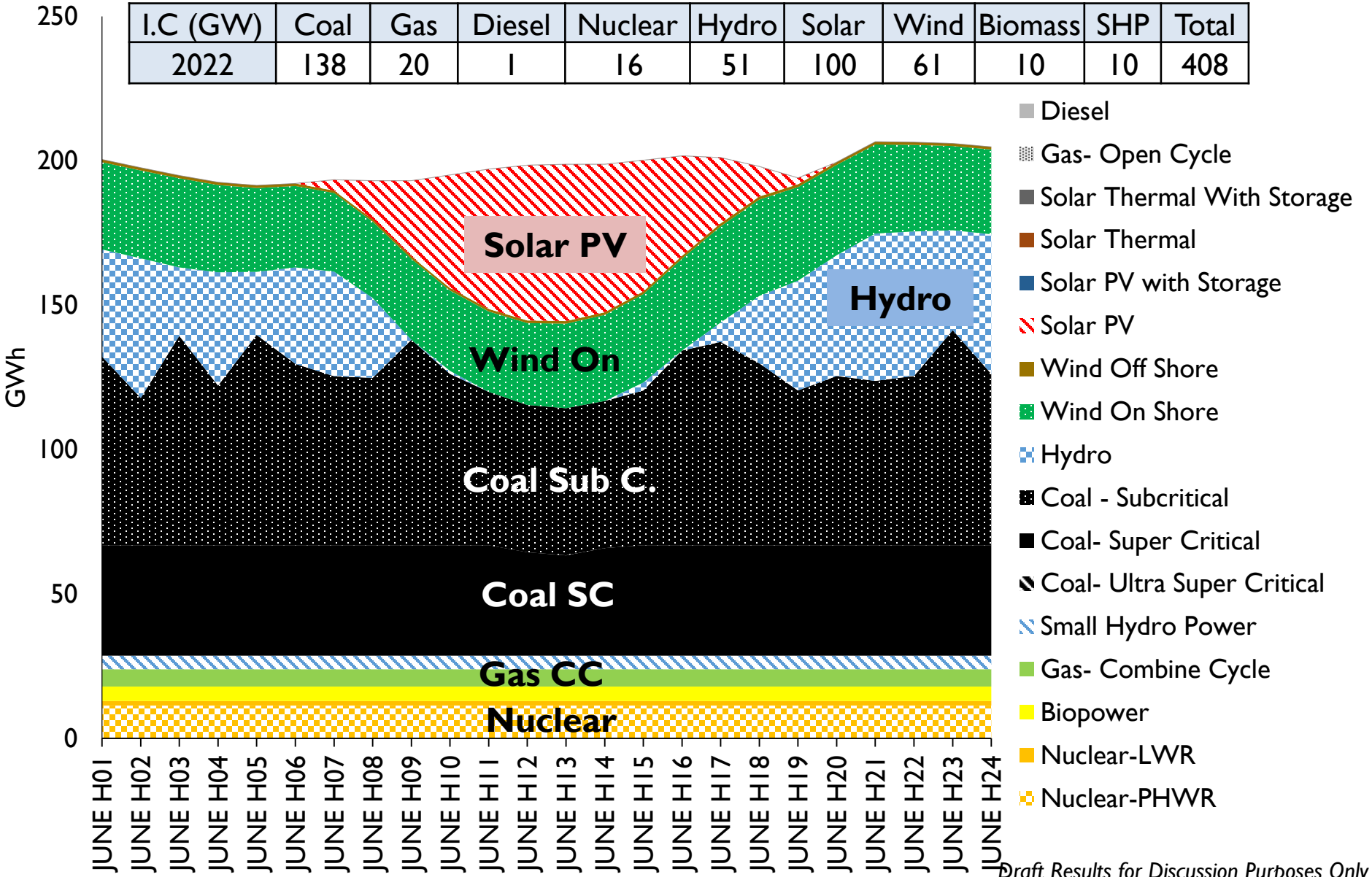

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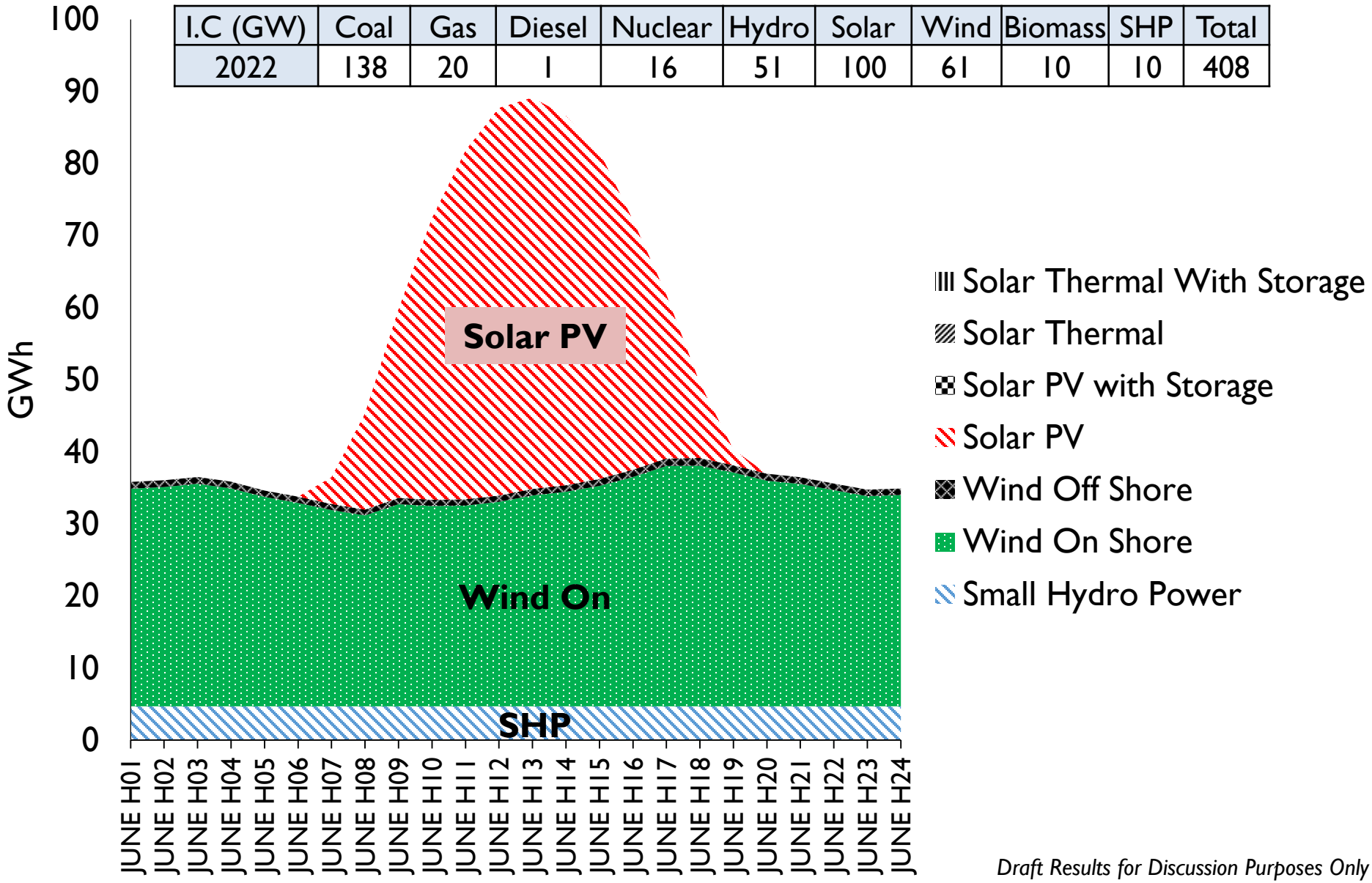

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Monthly Average- Electricity Generation (GWh) - 2022

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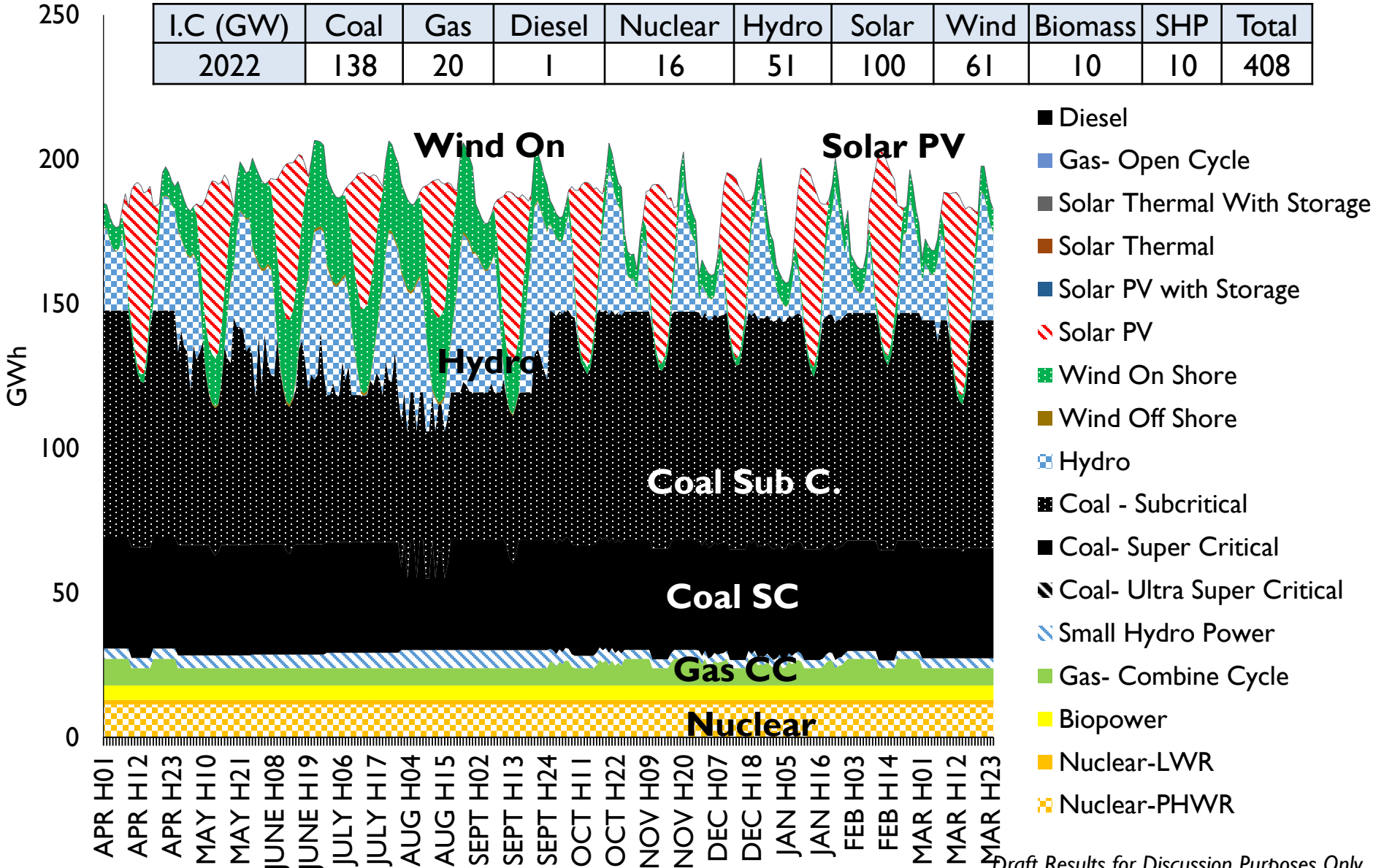

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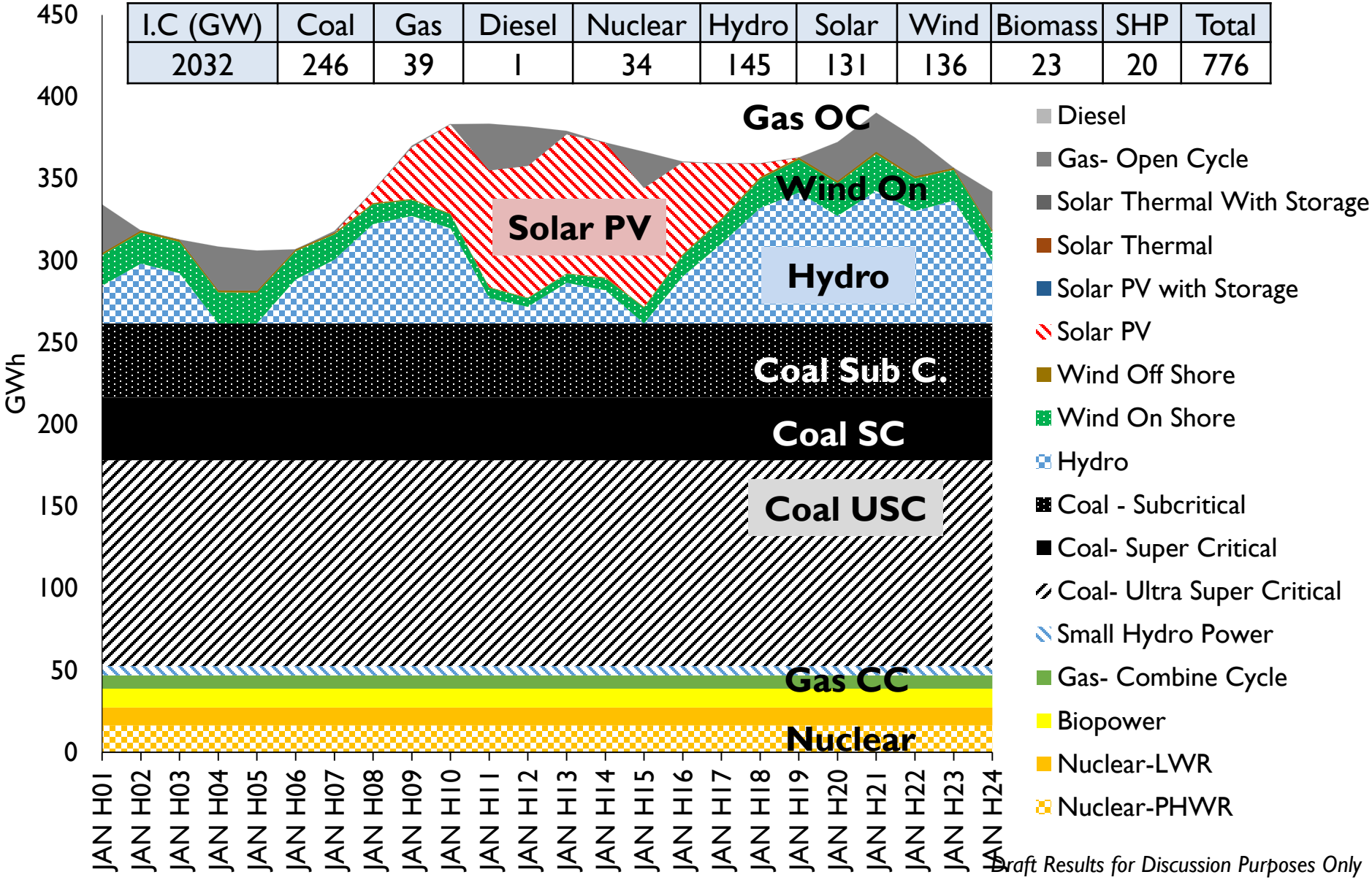
Typical One Day Generation in January 2032 (GWh)

I.C (GW)	Coal	Gas	Diesel	Nuclear	Hydro	Solar	Wind	Biomass	SHP	Total
2032	246	39	1	34	145	131	136	23	20	776



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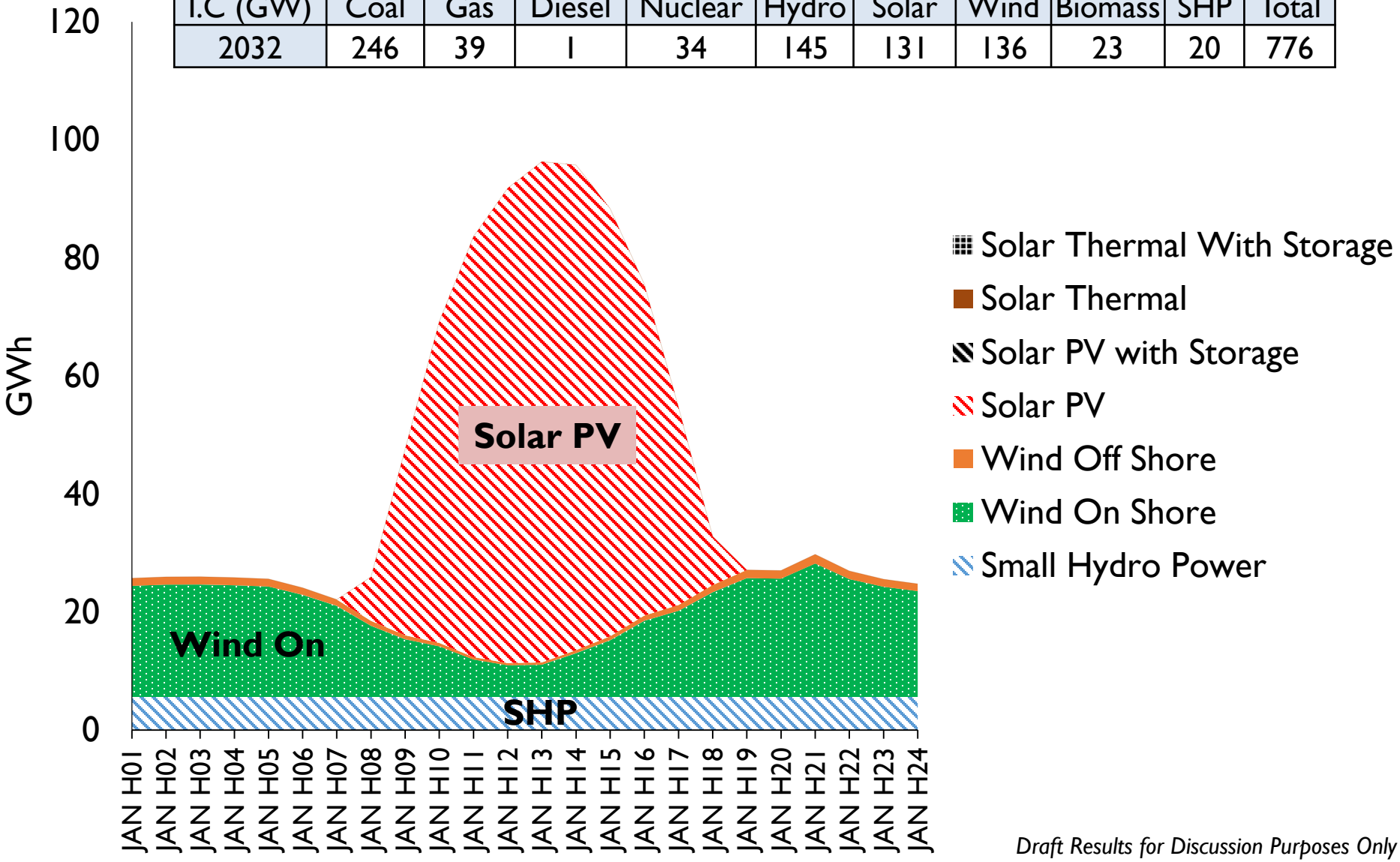

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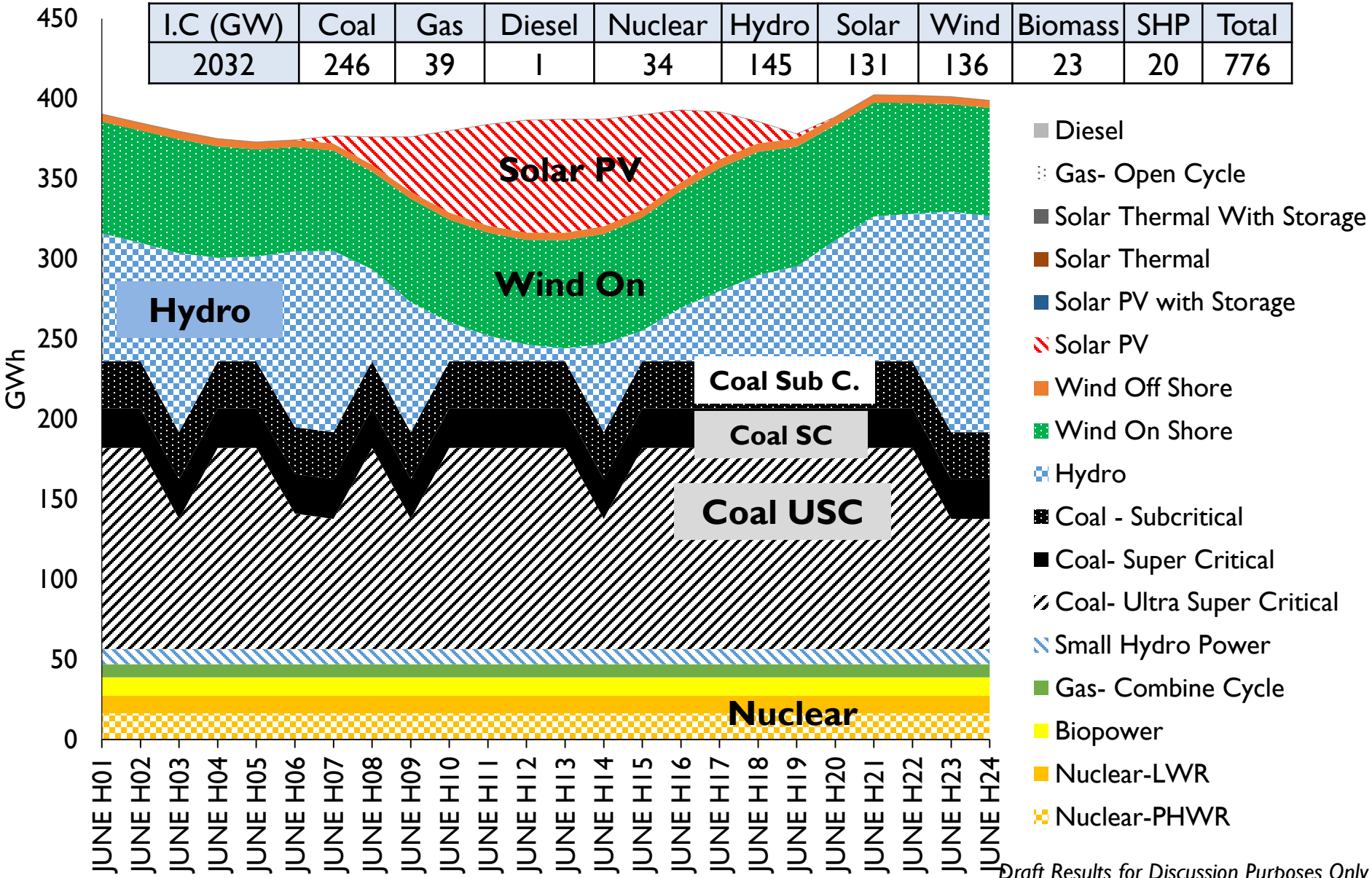

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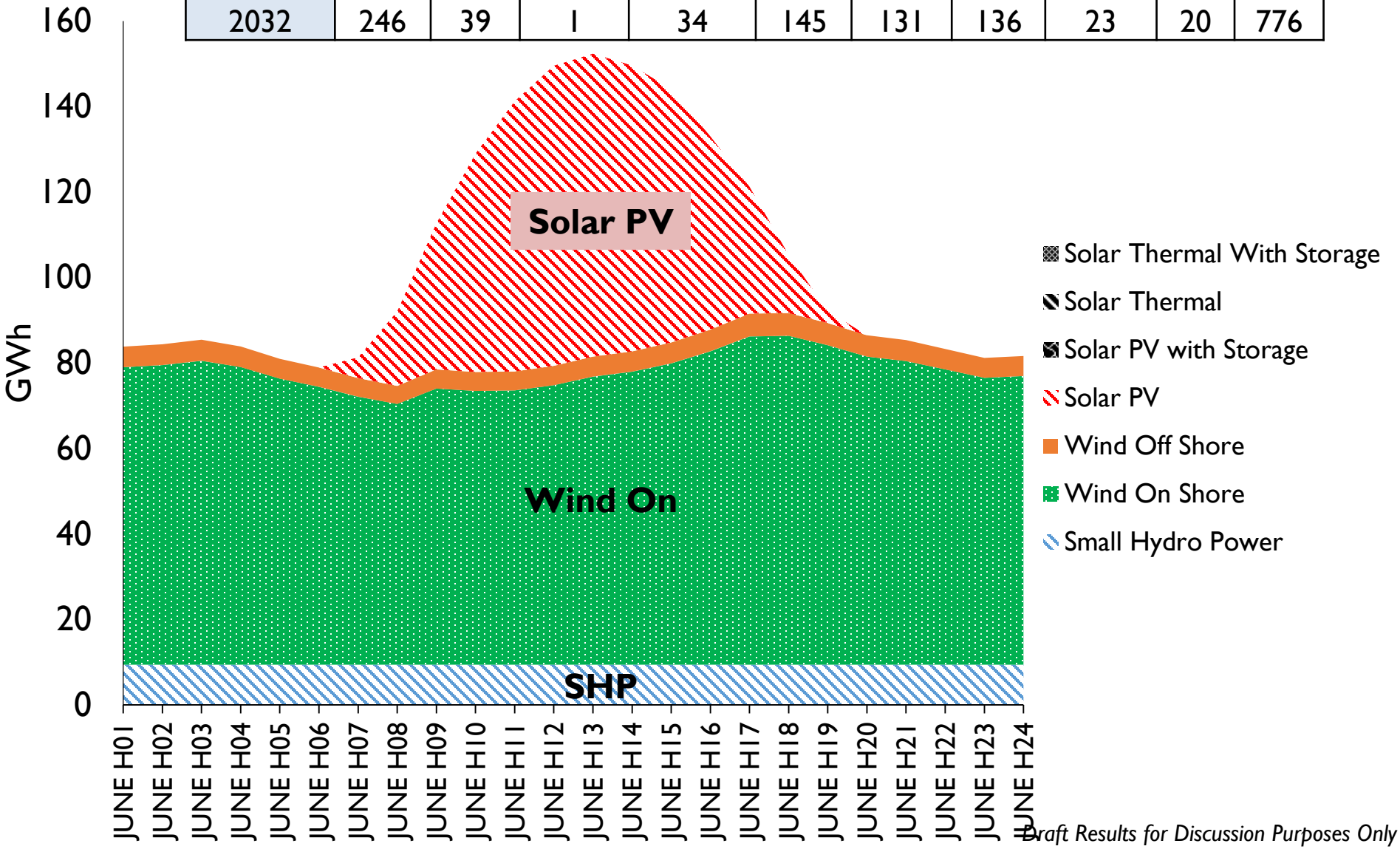

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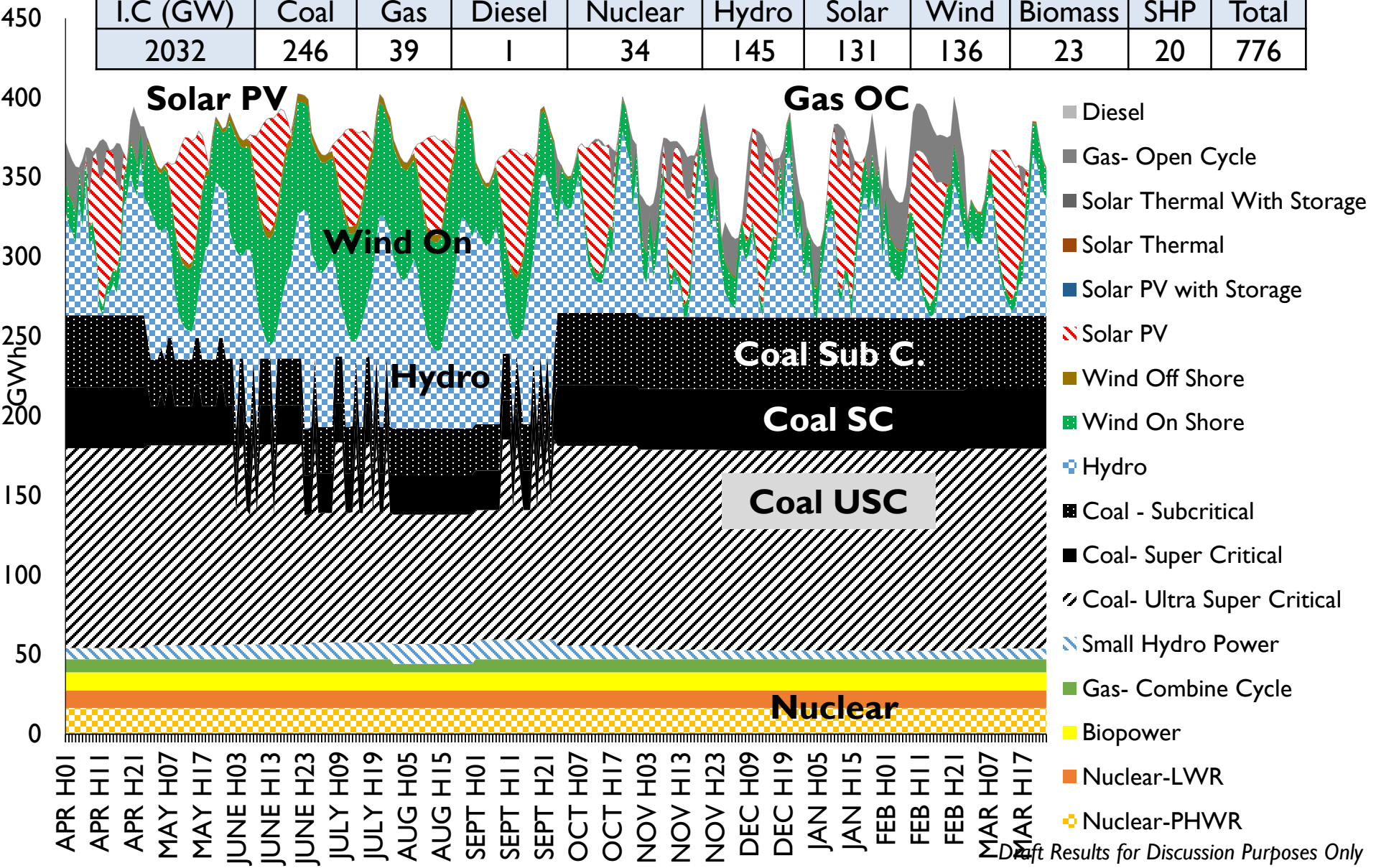

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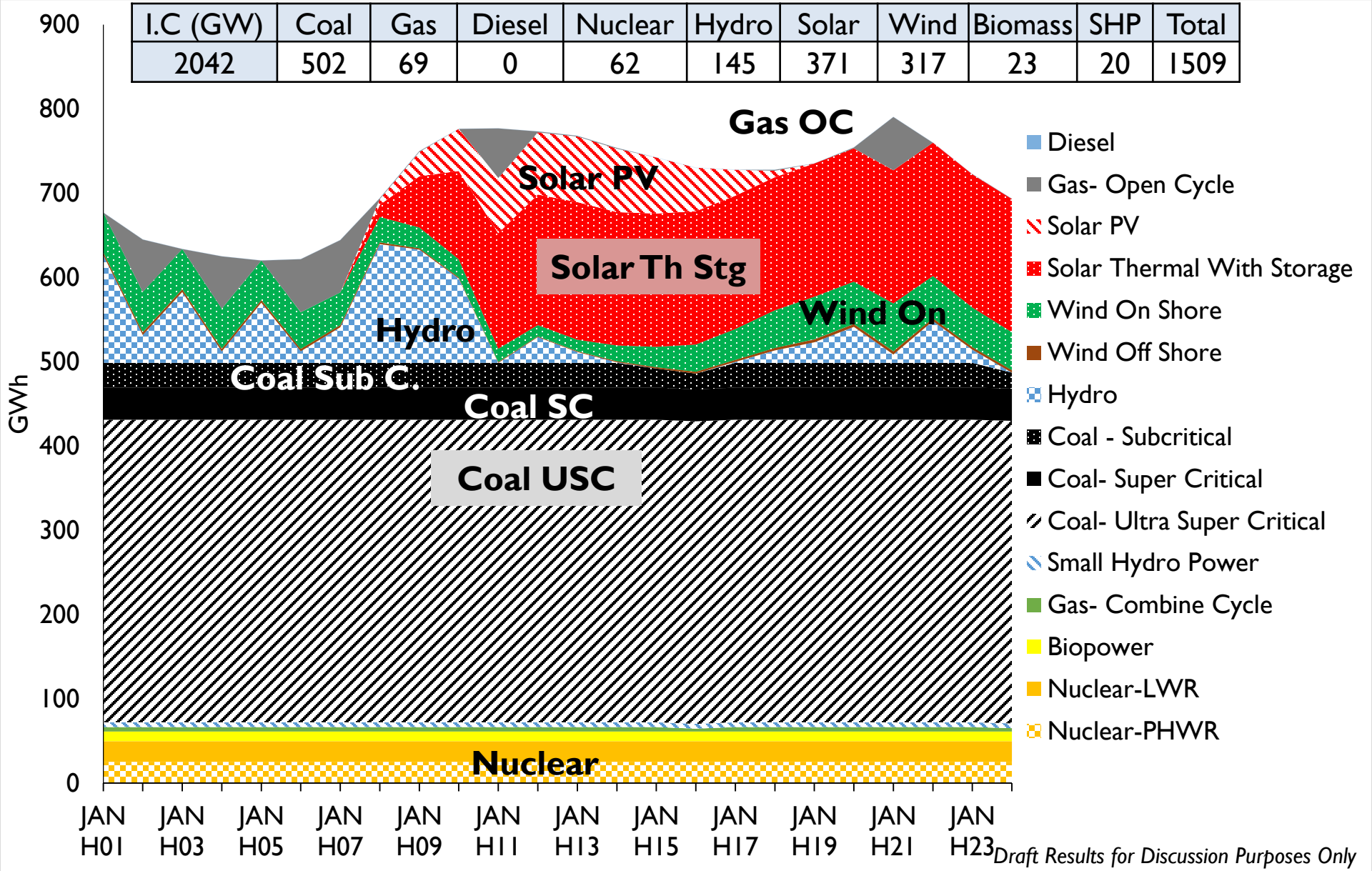
Typical One Day Generation in January 2042 (GWh)

I.C (GW)	Coal	Gas	Diesel	Nuclear	Hydro	Solar	Wind	Biomass	SHP	Total
2042	502	69	0	62	145	371	317	23	20	1509



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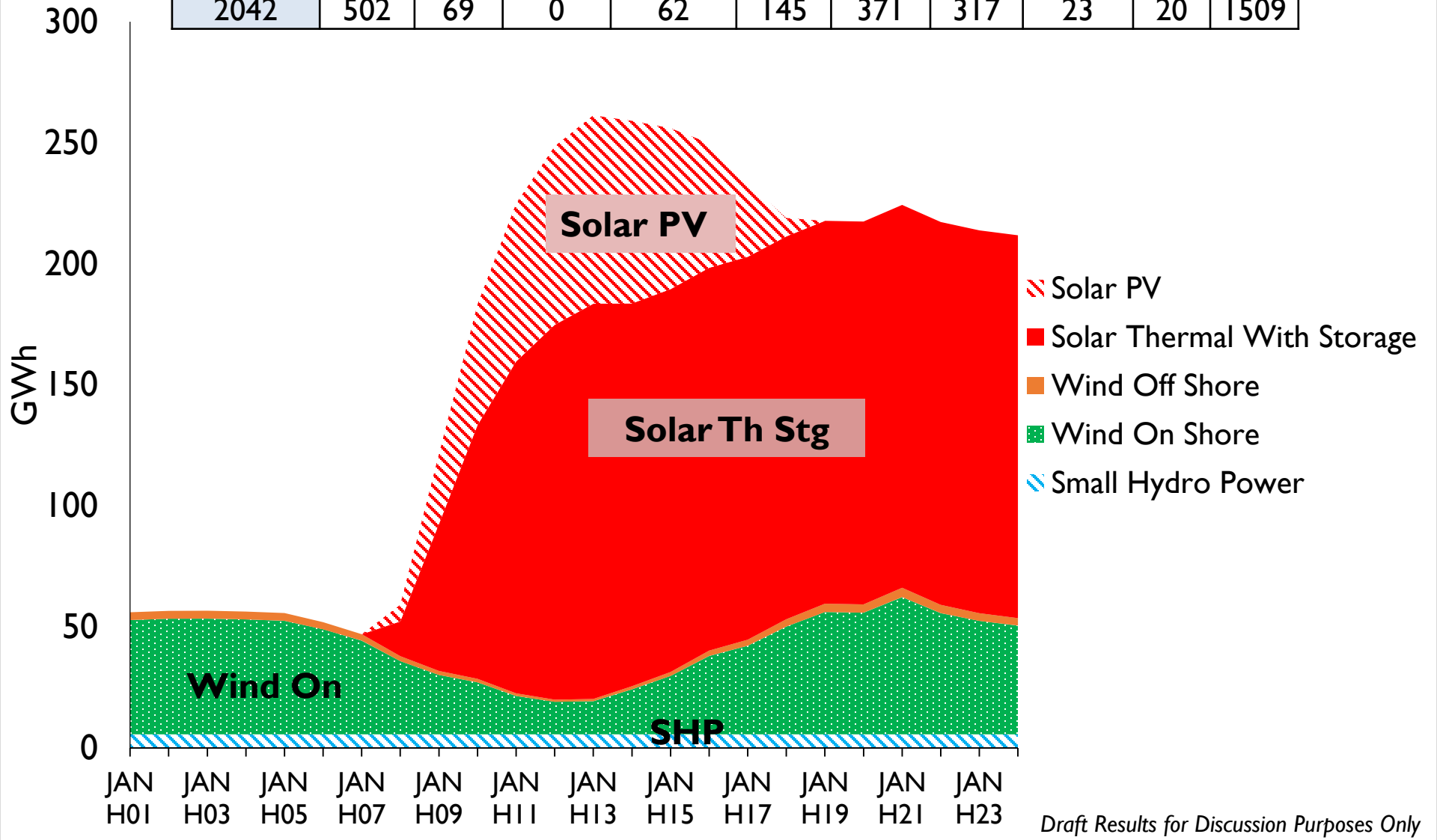

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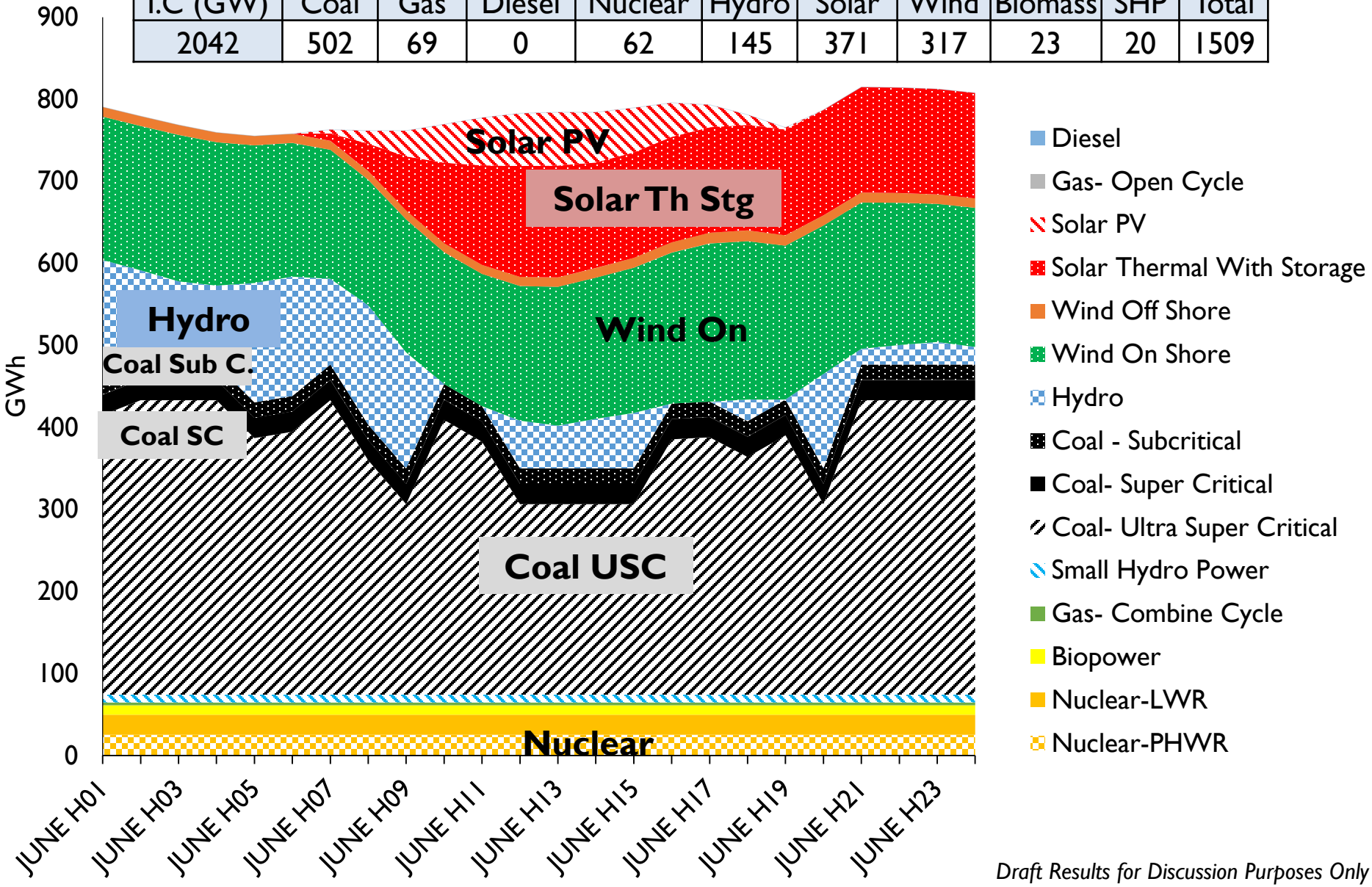

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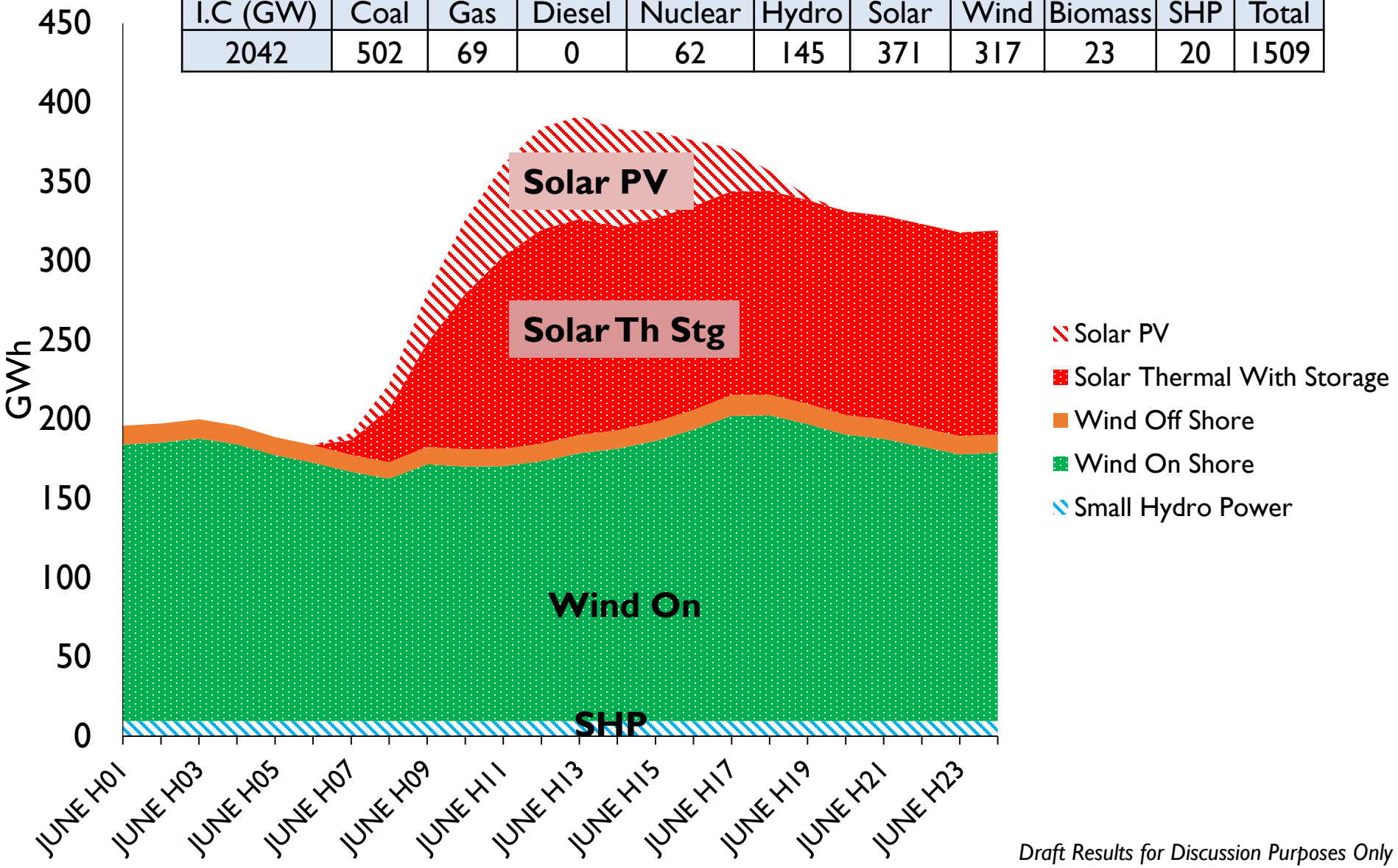

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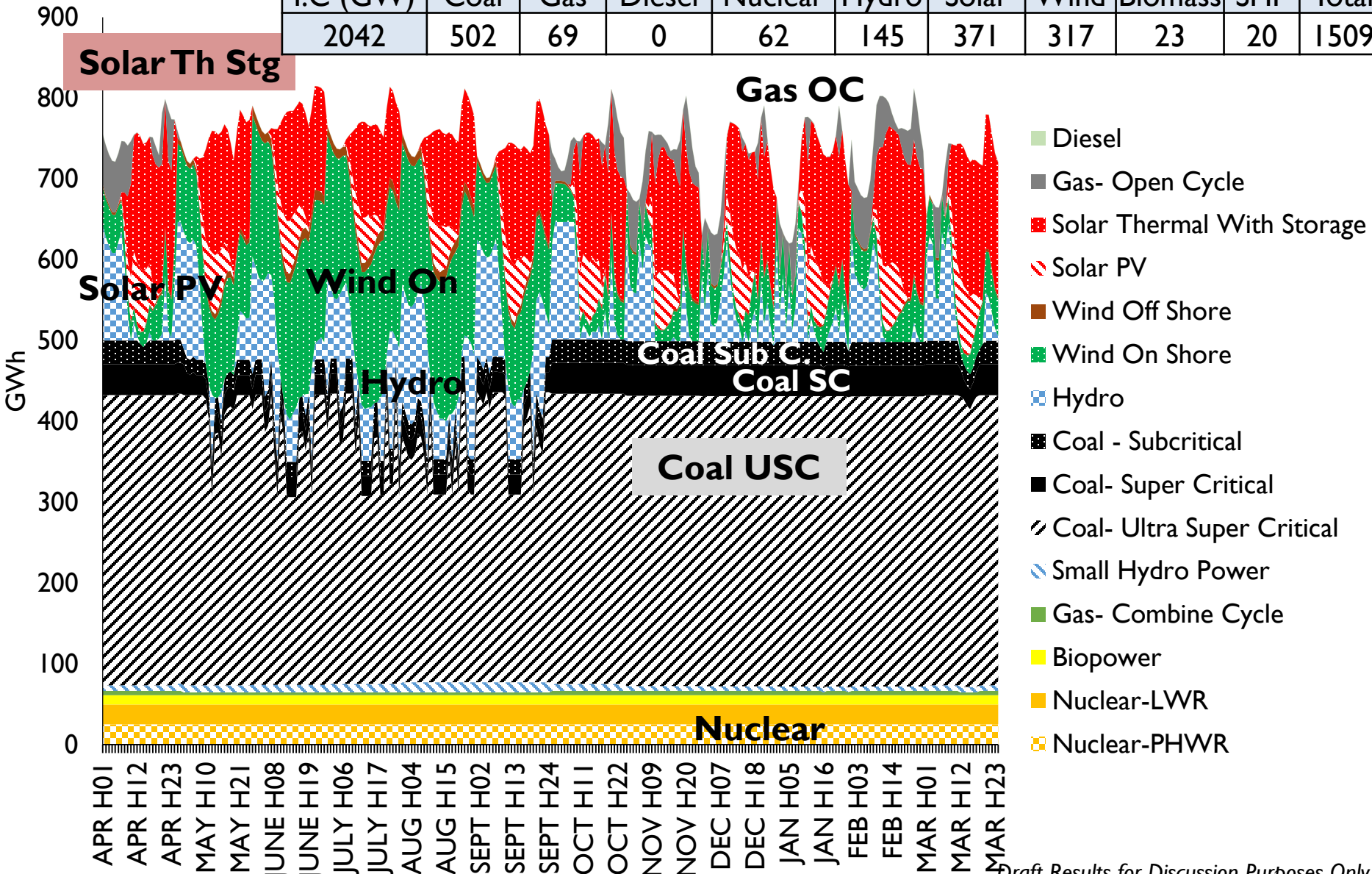

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Coal Capacity Ramping

Year	2017	2022	2027	2032	2037	2042	2047
Coal Installed Capacity (GW)	138	186	186	246	387	502	493

Max. Ramp up	GW per Hour	25	28	28	44	92	127	148
Max. Ramp Down	GW per Hour	25	22	22	44	90	127	127

Max. Ramp up	MW per Min	423	470	470	739	1535	2114	2465
Max. Ramp Down	MW per Min	423	369	369	739	1496	2112	2112

Coal Capacity Ramping

Year	2017	2022	2027	2032	2037	2042	2047
Coal Installed Capacity (GW)	138	186	186	246	387	502	493

Capacity Ramping (in MW per min) as % of Total Installed Coal Capacity

Change in Ramping up	0.31%	0.25%	0.25%	0.30%	0.40%	0.42%	0.50%
Change in Ramping Down	0.31%	0.20%	0.20%	0.30%	0.39%	0.42%	0.43%

Capacity Ramping (in GW per hour) as % of Total Installed Coal Capacity

Change in Ramping up	18%	15%	15%	18%	24%	25%	30%
Change in Ramping Down	18%	12%	12%	18%	23%	25%	26%

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India TIMES Model Assumptions

Capital and O&M Cost Assumed- 2012 price level

Technology	Capex 2012 (INR Cr/ MW)	O&M 2012 (INR Lakh/ MW)
Coal Sub-Critical	4.8	12
Coal Super-Critical	5.3	13
Coal Ultra Super Critical	6.1	15
Coal IGCC	10.0	25
Gas-Open Cycle	2.25	3.4
Gas Combined Cycle	3.6	9.0
Nuclear Light Water Reactor	21	52
Nuclear Pressurized Heavy Water Reactor	8.3	20
Wind- On-Shore	6	9
Wind- Off-Shore	18	13
Large Hydro	9.5	31
Small Hydro Plants	6.5	20
Bio Power Plants	4.5	18

- **For Solar- Assuming Technological cost reduction**

Technology	Capex 2012 (INR Cr/ MW)	Capex 2047 (INR Cr/ MW)	O&M 2012 (INR Lakh/ MW)	O&M 2047 (INR Lakh/ MW)
Solar PV- without Storage	8	3.3	12	4
Solar PV- with Storage	16.5 (2017)	9.8	41.14 (2017)	24.51
Solar Thermal- without Storage	12	7.7	15	9.5
Solar Thermal- with Storage	19.2	10.7	24	13.4

Fuel Cost- 2012 price level

Fuel	Price	Cal. Value
Domestic coal	1317 INR per ton	3541 Kcal/Kg
Imported Coal	5119 INR per ton	5500 Kcal/Kg
Biomass	2.4 INR per Kg	3752 Kcal/Kg
Domestic Natural Gas	8.387 INR per SCM	10000 Kcal/SCM
Imported LNG	10 USD/MMBTU	10000 Kcal/SCM
Natural Uranium	7.47 INR Cr/Ton (excluding enrichment cost)	

Plant Life Assumed

Technology	Plant Life Assumed (in Years)
Nuclear Power Plants	50
Hydro Plants	50
Coal based power plants	40
Gas Based Power Plants	40
Small Hydro Power Plants	35
Solar Based Power Plants	25
Wind Based Power Plants	25
Bio Power Plants	20

Levelized Cost of Electricity (in INR per kWh)

- LCOE at 2012 price levels
- Capex, O&M, Fuel Cost and Plant Life as shared in previous slides

Technology	4% discount rate	10% discount rate	10% discount rate with plant life of 25 years
Sub Critical Coal Plant- Domestic Fuel	1.55	1.88	1.93
Super Critical Coal Plant- Domestic Fuel	1.39	1.75	1.81
Ultra Super Critical Coal Plant- Domestic Fuel	1.36	1.78	1.84
IGCC Coal Plant- Domestic Fuel	1.72	2.41	2.52
Sub Critical Coal Plant- Imported Fuel	3.15	3.48	3.53
Super Critical Coal Plant- Imported Fuel	2.67	3.04	3.09
Ultra Super Critical Coal Plant- Imported Fuel	2.48	2.90	2.96
IGCC Coal Plant- Imported Fuel	2.77	3.46	3.57
Open Cycle Gas Plant-Domestic Fuel	2.12	2.28	2.30
Combine Cycle Gas Plant- Domestic Fuel	1.68	1.92	1.96
Open Cycle Gas Plant-Imported Fuel	5.66	5.81	5.84
Combine Cycle Gas Plant- Imported Fuel	4.09	4.34	4.37
Hydro Plant	2.14	3.62	3.87
SHP	1.64	2.64	2.77
Solar PV Plant	3.99	6.32	6.32
Solar PV with Storage	4.96	7.53	7.53
Solar Thermal	5.80	9.29	9.29
Solar Thermal with Stg	4.55	7.29	7.29
Bio Power	1.17	1.62	1.54

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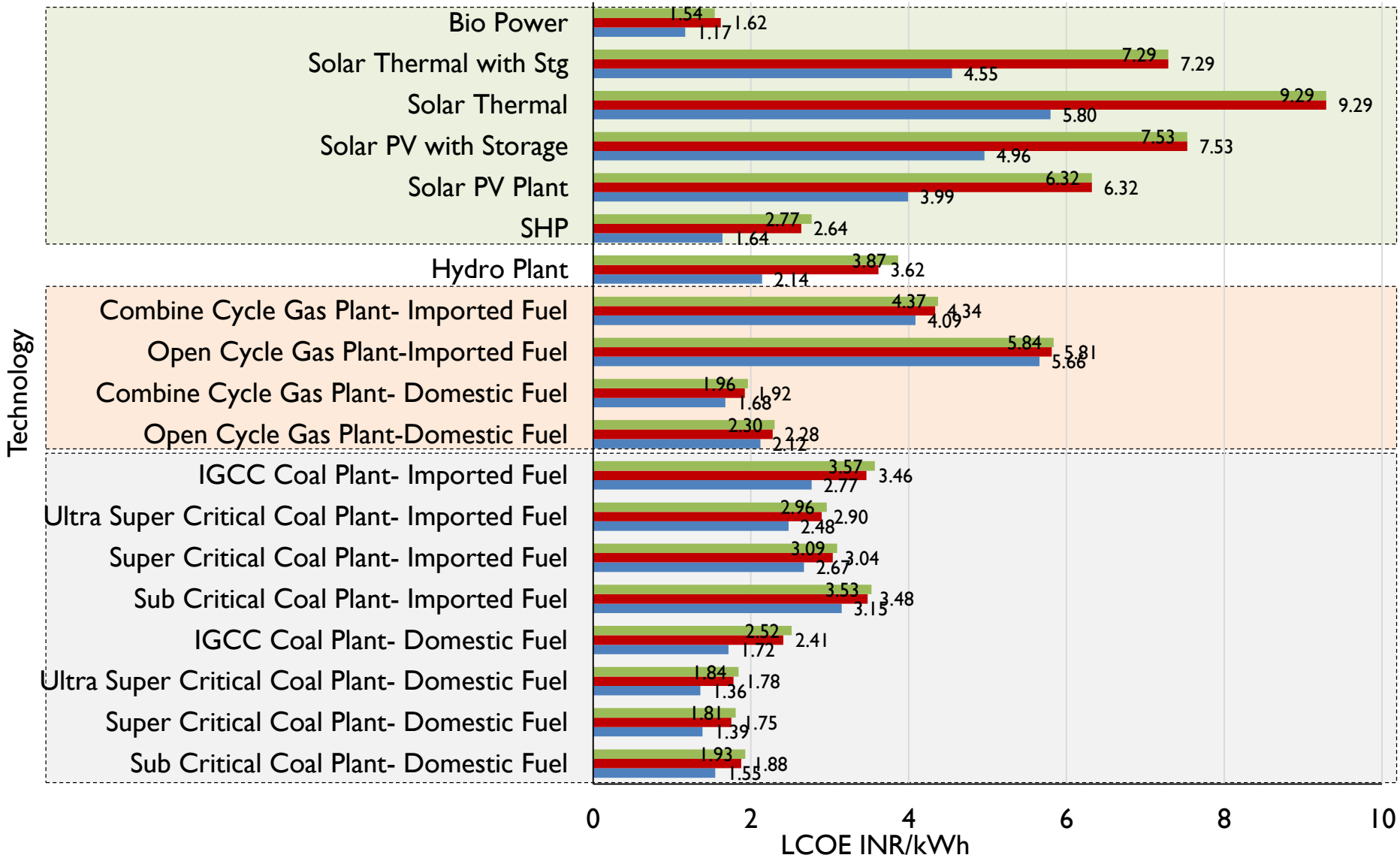
Levelized Cost of Electricity-2012 price levels (in INR per kWh)



PLF/CUF Assumed

		Monthly PLF/CUF											
Technology	**Annual PLF/CUF**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Hydro	40%	35%	43%	46%	52%	62%	61%	42%	30%	28%	28%	26%	34%
SHP	40.71%	35%	44%	47%	53%	63%	62%	43%	31%	28%	28%	27%	34%
Bio Power	50%												
Nuclear	80%												
Gas CC	55% (Lower Bound)- 85% (Upper Bound)												
Coal	55% (Lower Bound)- 85% (Upper Bound)												
Wind- On Shore	21.18%	Modelled at Hourly Level											
Wind- Off Shore	33%	Modelled at Hourly Level											
Solar PV without Storage	18%	Modelled at Hourly Level											
Solar PV with Storage	37%	Modelled at Hourly Level											
Solar Thermal without Storage	18%	Modelled at Hourly Level											
Solar Thermal with Storage	37%	Modelled at Hourly Level											

Thank You