REPORT
OF

COMMITTEE ON OPTIMAL ENERGY MIX IN POWER GENERATION ON MEDIUM AND LONG TERM BASIS

01-01-2018

Government of India
MINISTRY OF POWER
Central Electricity Authority
<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>1</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>3</td>
</tr>
<tr>
<td>2 MISSION STATEMENT</td>
<td>5</td>
</tr>
<tr>
<td>3 OPTIMAL GENERATION MIX STUDIES</td>
<td>6</td>
</tr>
<tr>
<td>4 INTEGRATION OF RENEWBALE ENERGY SOURCE</td>
<td>20</td>
</tr>
<tr>
<td>5 ROAD-MAP TO REDUCE DEPENDENCE ON IMPORT OF FUEL FOR POWER GENERATION</td>
<td>29</td>
</tr>
<tr>
<td>6 EMERGING TECHNOLOGIES</td>
<td>32</td>
</tr>
<tr>
<td>7 CONCLUSIONS</td>
<td>34</td>
</tr>
<tr>
<td>ANNEXURE-A CONSTITUTION OF COMMITTEE MOP LETTER DATED 27.10.2017</td>
<td></td>
</tr>
<tr>
<td>ANNEXURE-B MINUTES OF MEETING</td>
<td></td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

Government of India is committed to achieve Energy Autonomy and to provide Clean, Affordable, Reliable and Sustainable Power for All. Government of India has made international commitment (INDC) to have about 40% cumulative electric power installed capacity from non-fossil fuel based energy resources by the year 2030 and to reduce the emissions intensity of its GDP by 33% to 35% by the year 2030 from year 2005 level.

Government of India has set a target of 175 GW of Installed Capacity from Renewable Energy Sources (RES) by March 2022. Emphasis is also being given to the development of non-fossil fuel based power generation i.e. hydro to the extent possible and shifting towards more efficient supercritical technologies for Coal based power plant.

The base case scenario of Generation planning studies, carried out for National Electricity Plan, has shown that with committed capacity addition of Hydro 6,823 MW, Gas 406 MW, Nuclear 3,300 MW, RES 1,17,756 MW (Total RES capacity by 2022 to be 175 GW), with a retirement of coal based capacity of 22,716 MW and coal based capacity addition of 47,855 MW during the years 2017-22, the energy and peak demand in the year 2021-22 can be met easily with coal based plants being underutilized. As the conventional generation capacities are already at advanced stage of construction, there is not much scope in optimizing the generation mix by the year 2021-22.

However, Studies have been carried out for the period 2022-27, to find out the optimal generation mix. Two scenarios have been studied by considering INDC’s Targets and another by considering a boost to hydro power. The studies show that even with 1,25,000 MW installed capacity from RES (capacity addition 100,000 MW during 2017-22 and capacity addition of 25,000 MW during 2022-27) and committed capacity addition from Hydro and Nuclear, INDC targets can be achieved. Another scenario has been carried out by considering higher Hydro installed capacity of 80,000MW by 2027. It has been found that in this scenario, generation mix, 60% of the installed capacity would be from the non-fossil fuel and 40% from the fossil fuel.

With 175 GW of installed capacity from RES by the year 2021-22, it is estimated that the frequency of ramping requirement will increase with maximum positive ramping requirement of 400 MW/min. With the existing and proposed capacity addition, the ramping requirement of 400 MW/min can be achieved, if all generating stations exploit their inherent ramping capability and are flexible to operate.
Hydro and gas based generation can efficiently and effectively provide balancing and ramping requirements of the Grid in view of high RE integration. Government of India has been assisting the neighboring countries in the development of the hydropower potential for mutual benefits along with harnessing country’s potential of hydropower. Coordinated scheduling and utilization of hydro generation for providing balancing and peaking can help cope with the huge target of renewable capacity addition. The availability of domestic gas has limited the utilization of gas-based power plants for balancing the grid. However, combined cycle gas stations can provide peaking and balancing capacity to some extent if gas supply contracts are modified to include clauses like allowing non-uniform consumption of gas.

For reduction in import of fuels, efforts are being made to augment the production of indigenous coal by various means including adoption of latest state-of-art mining technology. It is envisaged that, in future, requirement of coal for the power stations would be almost completely met by the indigenous coal.

Introduction of new technologies like ultra-supercritical technology, battery storage, electric vehicles etc will play a major role in addressing environmental and Grid security concerns.
1. INTRODUCTION

In the Brain Storming Session chaired by Hon’ble Minister of State (I/C) for Power and Renewable Energy with officers of Ministry of Power (MoP) and MNRE on 9.10.17, it was decided, inter-alia, to constitute a Committee to give recommendations on the optimal energy mix in power generation on medium and long-term basis. Ministry of Power vide Order No.-33/12/2017-R&R (Part-2) dated 27/10/2017 (Annexure-A) constituted a Committee to give recommendations on the optimal energy mix in power generation on medium and long-term basis, with the following composition from Ministries/Organization as under:

i) Chairperson (CEA) - Chairman
ii) Joint Secretary (Thermal), MOP - Member
iii) CMD, NTPC - Member
iv) CMD, NHPC - Member
v) Representative from MNRE - Member
vi) Representative from NITI Aayog - Member
vii) Representative from Tamil Nadu - Member
viii) Representative from Uttar Pradesh - Member
ix) Representative from Maharashtra - Member
x) Chief Engineer (OM, R&R), MOP - Convener

The Terms of Reference of the subgroup are given below:-

➢ Formulate the mission statement for aiming at energy autonomy, clean, affordable, reliable and sustainable power for all;

➢ Year-wise, fuel-wise optimal generation mix in the next 15year-time horizon taking into account India’s Nationally Determined Contribution (INDCs) under the Paris Climate Agreement, economic growth, environmental concerns, grid security and adaptability to the changing technology landscape in the power sector;

➢ Recommend the optimal balancing requirement required in the grid and develop scenarios for integration of renewable at various energy-mix levels including respective cost of integration;

➢ Suggest the road map to reduce the dependence on import of fuel for power generation;

➢ The base line of the study would be the present existing scenario. Committee should factor in the environmental concerns. Grid security and adaptability to the changing Technology in power sector;
- Any other issues to achieve objectives of the mission statement.

The following members have also been co-opted in the Committee:

1. Member (Planning), CEA
2. CEO, POSOCO
3. Chief Engineer (IRP), CEA
4. Chief Engineer (FM), CEA
5. Chief Engineer (TETD), CEA
6. Representative from BEE
7. Representative from CERC

Three meetings of the committee were held in CEA on 07/11/2017, 28/11/2017 and 12/12/2017. Minutes of the meeting is enclosed at Annexure –B.
MISSION STATEMENT

“Aim to achieve Energy Autonomy and provide Clean, Affordable, Reliable and Sustainable Power for All”
TOR-2

OPTIMAL GENERATION MIX

1. Introduction

Electricity is one of the key enablers for achieving socio-economic development of the country. The economic growth leads to growth in demand of power. To meet this demand, the capacity addition has to be planned very optimally in view of the limited availability of fuel resources for generation.

Generation capacity augmentation is the most vital component amongst various modes adopted for meeting the ever-increasing demand of power to achieve the targeted growth rate. Coal is the major source for power generation in our country however, since Low Carbon Growth Strategy has to be followed, other generation options have to be harnessed in the optimum manner.

Fuel Options available for Power Generation are:

- Conventional Sources – Coal and lignite, Hydro, Nuclear, Natural gas
- Non-Conventional Renewable Energy Sources- Solar, Wind, Biomass, small hydro, etc.

Optimum Generation mix is an optimization problem, in which the objective function is to minimize the following:

1) the costs associated with operation of the existing and committed generating stations,
2) the annualized/ levelised capital cost and operating cost of new generating stations, and
3) Cost of energy not served in such a way to satisfy the different constraints in the system such as:

- Renewable capacity addition targets fixed by Government.
- Must Run Status for Renewable Energy Sources like Solar, Wind etc.
- LOLP (Loss of Load Probability).
- ENS (Energy Not Served).
- Limited Scope in Nuclear and Hydro Generation Expansion.
- Provision of Reserve Margin
- International commitments by India (Paris Agreement).
- Emission limits if any.
2. Installed Capacity at the end of 12th Five Year Plan i.e 31.03.2017

Total Installed Capacity as on 31.03.2017 i.e. at the end of 12th Five Year Plan was 326.84 GW, which comprise of 44.47 GW from Hydro, 218.328 GW from Thermal, 57.26 GW from RES and 6.78 GW from Nuclear. The detailed breakup of the Total installed capacity as on 31.03.2017 and energy contribution from different sources during 2016-17 is given in Table 1 and Exhibit 1 respectively.

Table 1
INSTALLED CAPACITY AT THE END OF 12TH PLAN (i.e. UPTO 31.03.2017)
(FIGURES IN MW)

<table>
<thead>
<tr>
<th>SECTOR</th>
<th>HYDRO</th>
<th>THERMAL</th>
<th>NUCLEAR</th>
<th>R.E.S</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>COAL</td>
<td>GAS</td>
<td>DIESEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATE</td>
<td>29683.00</td>
<td>64685.50</td>
<td>7257.95</td>
<td>363.93</td>
<td>72307.38</td>
</tr>
<tr>
<td>PRIVATE</td>
<td>3144.00</td>
<td>73142.38</td>
<td>10580.60</td>
<td>473.70</td>
<td>84196.68</td>
</tr>
<tr>
<td>CENTRAL</td>
<td>11651.42</td>
<td>54335.00</td>
<td>7490.83</td>
<td>0.00</td>
<td>61825.83</td>
</tr>
<tr>
<td>TOTAL</td>
<td>44478.42</td>
<td>192162.8</td>
<td>25329.38</td>
<td>837.63</td>
<td>218329.8</td>
</tr>
<tr>
<td>%</td>
<td>13.61</td>
<td>58.79</td>
<td>7.75</td>
<td>0.26</td>
<td>66.80</td>
</tr>
</tbody>
</table>

It can be seen from above that although the installed capacity of thermal power is about 67 %, the generation from these sources is around 80%.
3. Capacity and generation mix of the country

Exhibit 2 and Exhibit 3 depict the capacity and generation mix historically. It can be seen that share of hydro in installed capacity has reduced in recent year with increase in share of renewable energy.

**EXHIBIT 2**

Installed Generation capacity mix of the country since the year 1980

**EXHIBIT 3**

Source wise Electrical energy mix of the country since the year 2006
4. Optimal Capacity Mix studies

i. Generation expansion planning studies for the National Electricity Plan has been carried out for the year 2021-22 and 2026-27 to find out the optimal capacity mix based on the Electricity demand assessed by the 19th Electric Power Survey (EPS) and also keeping in view various GOI initiatives like RES capacity Target by 2022, committed capacity etc.

ii. The estimated peak demand (MW) and Energy requirement (BU) in the years 2021-22 and 2026-27 are given below in Table 2.

Table 2
Projected Electricity Demand (As per 19th EPS)

<table>
<thead>
<tr>
<th>Year</th>
<th>Electrical Energy Requirement (BU) Ex Bus</th>
<th>Peak Electricity Demand (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021-22</td>
<td>1566*</td>
<td>225.751</td>
</tr>
<tr>
<td>2026-27</td>
<td>2047*</td>
<td>298.774</td>
</tr>
</tbody>
</table>

*considering energy contribution of solar roof top.

iii. The results of the generation planning studies for the National Electricity Plan are as under:

a. In the base case for the period 2017-22, committed capacity addition of Hydro 6,823 MW, Gas 406 MW, Nuclear 3,300 MW, RES 1,17,756 MW (Total RES capacity by 2022 to be 175 GW) has been considered. Also a coal based capacity of 22,716 MW is considered for retirement due to old and inefficient units and due to Environment norms. It was found that only 6,445 MW additional coal based capacity would be required during 2017-22 to meet the peak demand and energy requirement in the year 2021-22 as per the 19th EPS (the CAGR works out to be 6.18% during 2017-22). However, coal based capacity of 47,855 MW is at various stages of construction which is likely to be commissioned during 2017-22. The overall PLF during 2021-22 of coal based capacity (including 47,855MW) is likely to be 56.5%.

b. In an alternate scenario (considering higher energy and peak requirement from base case), Energy Requirement of 1641 BU and Peak Demand of 237 GW to account for any change in demand due to shifting of captive load to the grid, slippage in Energy Efficiency targets etc) has been considered by taking a demand CAGR of 7.18%. Keeping the capacity addition from RES and Hydro, Retirement of units same as considered in base case, it is observed that coal based capacity addition of 19,700 MW may be required during 2017-22. However, 47,855 MW of coal-based plants are in different stages of construction and
would yield benefit during 2017-22. The overall PLF during 2021-22 of coal based capacity (including 47,855MW) is likely to be 68.5%.

c. For the period 2022-27, committed capacity addition of Nuclear- 6,800 MW, Hydro-12,000 MW and RES 1,00,000 MW has been considered. The study has also taken into account the Coal based capacity of 47,855 MW already under construction for benefits during 2017-22 and likely retirement of coal based capacity of 22,716 MW and 25,572 MW during 2017-22 and 2022-27 respectively. Study for the period 2022-27 reveals that a coal based capacity addition of 46,420 MW is required to meet the demand projections as per the 19th EPS for the year 2026-27.

d. The likely installed capacity from different fuel types at the end of 2021-22 in base case, works out to be 4,79,419 MW including 47,855 MW of Coal based capacity currently under construction and likely to yield benefits during 2017-22 and retiring a capacity of 22,716 MW. The projected installed capacity at the end of 2026-27 works out to be 6,19,066 MW. The details are given in Table 3 and Exhibit 4.

Table 3
Projected Installed capacity by the end of 2021-22 and 2022-27

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Installed Generation Capacity in 2021-22</th>
<th>%</th>
<th>Installed Generation Capacity in 2022-27</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>51,301</td>
<td>10.7</td>
<td>63,301</td>
<td>10.2</td>
</tr>
<tr>
<td>Coal + Lignite</td>
<td>2,17,302</td>
<td>45.3</td>
<td>2,38,150</td>
<td>38.5</td>
</tr>
<tr>
<td>Gas</td>
<td>25,736</td>
<td>5.4</td>
<td>25,735</td>
<td>4.2</td>
</tr>
<tr>
<td>Nuclear</td>
<td>10,080</td>
<td>2.1</td>
<td>16,880</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Total Conventional Capacity</strong> *</td>
<td><strong>3,04,419</strong></td>
<td><strong>63.5</strong></td>
<td><strong>3,44,066</strong></td>
<td><strong>55.6</strong></td>
</tr>
<tr>
<td><strong>Total Renewable Capacity</strong></td>
<td><strong>1,75,000</strong></td>
<td><strong>36.5</strong></td>
<td><strong>2,75,000</strong></td>
<td><strong>44.4</strong></td>
</tr>
<tr>
<td><strong>Total Installed Capacity</strong></td>
<td><strong>4,79,419</strong></td>
<td><strong>100.0</strong></td>
<td><strong>6,19,066</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

*Including 47,855 MW of Coal based capacity addition currently under construction, retirement of 22,716 MW and likely to yield benefits in 2017-22 and an additional 46,420 MW coal based capacity addition required during 2022-27. Also retirement of coal based capacity of 22,716 MW and 25,572 MW during 2017-22 and 2022-27 respectively has been taken into consideration.
The Projected Electrical Energy Generation during the year 2021-2022 would be 1,699 BU, which comprises of 1,071.80 BU from Thermal (Coal and Lignite), 327 BU from RES, 155.74 BU from Hydro, 62.64 BU from Nuclear and 82.62 BU from Gas and Diesel.

Exhibit 4

The Projected Generation (MU) during 2026-27 would be 2223BU, which comprises of 1239 BU from Thermal (Coal and Lignite), 518 BU from RES, 269BU from Hydro, 111BU from Nuclear and 86 BU from Gas and Diesel.

Exhibit 5
e) Comparison of Installed Capacity Mix at the end of year 2016-17, 2021-22 and 2026-27

As can be seen from the Exhibit 6 that share of installed capacity from Renewable energy is expected to dominate share of installed capacity at the end of year the year 2021-22 and 2026-27.

EXHIBIT 6(Figures in MW)

Also in terms of Electrical Energy generation mix, the share of RES generation would be around 19.24% of the total generation expected to come in the year 2021-22 and around 23.3% in the year 2026-27 (Exhibit- 7).
iv. International Commitment - INDC Targets

Under the Copenhagen Accord, India has pledged to reduce its CO₂ intensity (emissions per GDP) by 20 to 25 percent by 2020 compared to 2005 levels. Also in October 2015, India has submitted its Intended Nationally Determined Contribution (INDC) to UNFCCC. The key elements are:

- To reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005 level.
- To achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030, with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).
- To create an additional carbon sink of 2.5 to 3 billion tonnes of CO₂ equivalent through additional forest and tree cover by 2030.

Projected Achievements of INDCs

a. Installed capacity and share of non-fossil fuel

In March 2016, Percentage of Non- Fossil fuel in Installed Capacity was 33.20 %. It is found in the studies that it is likely to increase to 49.31% in March 2022 and 57.37 % in March 2027. However, as per INDC Target, the percentage of Non- Fossil Fuel in Installed Capacity is to be 40% by 2030. Table 4 below gives the percentage of non-fossil installed capacity by the end of 2022 and 2027.
Table 4

<table>
<thead>
<tr>
<th>Year</th>
<th>Installed Capacity (MW)</th>
<th>Installed Capacity of Fossil fuel (MW)</th>
<th>Installed Capacity of Non-Fossil** fuel (MW)</th>
<th>% of Non-fossil fuel in Installed Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>March,2016</td>
<td>3,26,833</td>
<td>2,18,330</td>
<td>1,08,503</td>
<td>33.20%</td>
</tr>
<tr>
<td>March,2022</td>
<td>4,79,419</td>
<td>2,43,038</td>
<td>2,36,381</td>
<td>49.31%</td>
</tr>
<tr>
<td>March,2027</td>
<td>6,19,066</td>
<td>2,63,885</td>
<td>3,55,181</td>
<td>57.37%</td>
</tr>
</tbody>
</table>

** Non Fossil Fuel – Hydro, Nuclear and Renewable Energy Sources

Note:
1. Including 47,855 MW of Coal based capacity addition currently under construction and likely to yield benefits in 2017-22 and an additional 46,420 MW coal based capacity addition required during 2022-27 & a coal based capacity considered for retirement being 22,716 MW during 2017-22 and 25,572 MW during 2022-27.
2. The actual % may change to the extent of thermal capacity materialising and actual retirement taking place during 2017-22 and 2022-27.

b. **CO₂ emissions Intensity from Power Sector**

In INDC target, India has also committed to reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005 level. In Generation Expansion planning studies, it is estimated that percentage reduction of emission intensity with respect to base year 2005 is to be 53.65%, which is way ahead than the INDC Target (Table 5).

Table 5

<table>
<thead>
<tr>
<th>Emission intensity kg/₹ GDP</th>
<th>2005</th>
<th>2022</th>
<th>2027</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Reduction in emission intensity base 2005</td>
<td>40.51</td>
<td>53.65</td>
<td></td>
</tr>
</tbody>
</table>

v. **ADDITIONAL SCENERIOS**

a. **SCENERIO-I:** Renewable Energy Sources Capacity Requirement to meet INDC target of 40% installed capacity from non-fossil fuel by 2030

As seen from Table 4 above that with the RES capacity target of 175GW by 2022 and proposed capacity from Hydro and Nuclear, share of Non-Fossil fuel in Installed Capacity, which is
currently at 33.20 %, is likely to increase to 49.31% by March 2022 and 57.37% by the end of year 2026-27.

Although there is not much scope in optimizing the generation mix by the year 2021-22, however, a study has been carried out to assess the minimum capacity addition requirement from RES to meet the INDC targets of 40% of the installed capacity from Non-fossil fuels by the year 2030. As the data available is upto the year 2027, the study was aimed to achieve INDC targets by the year 2027.

Studies for 2021-22 revealed that Renewable installed capacity of 1,00,000 MW and under construction coal based capacity addition of 47,855 MW, 6,823 MW of hydro, 3,300 MW of Nuclear and 406 MW of gas is sufficient to meet the target of 40% of the installed capacity from non-fossil fuels. The retirement of coal based capacity is kept same as in para 3(a) for the period 2017-22.

Table 5

<table>
<thead>
<tr>
<th>Total Installed capacity by 2021-22</th>
</tr>
</thead>
<tbody>
<tr>
<td>(FIGURES IN MW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sector</th>
<th>Installed Capacity (IC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2,17,302</td>
</tr>
<tr>
<td>Gas</td>
<td>25,736</td>
</tr>
<tr>
<td>Hydro</td>
<td>51,301</td>
</tr>
<tr>
<td>Nuclear</td>
<td>10,080</td>
</tr>
<tr>
<td>RES</td>
<td>1,00,000</td>
</tr>
<tr>
<td>Total</td>
<td>4,04,419</td>
</tr>
</tbody>
</table>

% of Non-fossil fuels in IC 40%
It is also seen from the studies that to meet the peak and energy requirement for the year 2026-27 and to fulfill the INDC commitment of 40% non-fossil fuel generation capacity by 2027, a Renewable Installed capacity of 125 GW by the end of 2026-27 will be sufficient, along with a capacity addition of 10,100 MW Nuclear (3,300 MW from 2017-22 and 6,800 MW from 2022-27), 18,823 MW Hydro (6,823 MW from 2017-22 and 12,000 MW from 2022-27) and 68,060 MW of coal based capacity during 2022-27. This coal based capacity addition is over and above 47,855 MW of coal based capacity already under construction for benefits during 2017-22. The retirement of coal based capacity is kept same as in para 3(c) for the period 2022-27.

The breakup of projected Installed capacity by 2026-27 is given below in Table 6 and Exhibit 9:

### Table 6

**Total Installed capacity by 2026-27**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Installed Capacity (IC) (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2,59,790</td>
</tr>
<tr>
<td>Gas</td>
<td>25,736</td>
</tr>
<tr>
<td>Hydro</td>
<td>63,301</td>
</tr>
<tr>
<td>Nuclear</td>
<td>16,880</td>
</tr>
<tr>
<td>RES</td>
<td>1,25,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,90,707</strong></td>
</tr>
<tr>
<td>% of Non-fossil fuels in total IC</td>
<td><strong>41.8%</strong></td>
</tr>
</tbody>
</table>
India has also committed to reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005 level as per the INDC. It is seen from the studies that with a Renewable Installed capacity of 125 GW by year 2027 and the proposed addition of 10,100 MW Nuclear (3,300 MW from 2017-22 and 6,800 MW from 2022-27) and 18,823 MW Hydro (6,823 MW from 2017-22 and 12,000 MW from 2022-27), emission intensity from power sector will reduce to 42.90% in 2027. However, the net reduction of CO₂ emissions will be less as emissions from thermal power stations will increase due to frequent cycling and ramping of the plants when compared with their steady state operation. It is estimated that heat rate of subcritical machines (proposed for flexible operation due to integration of renewable energy) will increase by 1.5% due to part load operation, resulting in increase of 1.5% in CO₂ emissions.

<table>
<thead>
<tr>
<th>Years</th>
<th>2005</th>
<th>2022</th>
<th>2027</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission intensity kg/₹ GDP</td>
<td>0.015548</td>
<td>0.010286</td>
<td>0.008878</td>
</tr>
<tr>
<td>% Reduction in emission intensity base 2005</td>
<td></td>
<td>33.84</td>
<td>42.90</td>
</tr>
</tbody>
</table>
b. SCENERIO-II : Capacity Requirement with Hydro installed capacity of 80 GW by the year 2027

A study has also been carried out to assess the capacity addition requirement from coal based power plants in case hydropower capacity addition is given impetus and increased to total installed capacity of 80 GW by March 2027. This is with the assumption that around 50% of the country’s total hydro potential (approx. 148000 MW) is exploited by the March 2027.

It is seen from the studies that to meet the peak and energy requirement for the year 2026-27, a capacity addition of 78,775 MW is required from coal-based power plants during the years 2017-27. However, a coal based capacity of 47,855 MW is already under construction for likely benefit up to March 2022 therefore only 30,920 MW will be needed during 2022-27, along with this coal based capacity addition of 78,775 MW, a capacity addition of 10,100 MW Nuclear (3,300 MW from 2017-22 and 6,800 MW from 2022-27), 35,323 MW Hydro (6,823 MW from 2017-22 and 28500 MW from 2022-27). Renewable Installed capacity of 275 GW by the end of 2026-27 is also considered in this scenario. It is also assumed that only present level of domestic gas will be available for gas based plants upto the year 2026-27 (i.e present PLF of 22% for gas based power plants).

The breakup of projected Installed capacity in high hydro scenario by 2026-27 is given below in Table 8 and Exhibit 10:

Table 8

<table>
<thead>
<tr>
<th>Sector</th>
<th>Installed Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2,22,652</td>
</tr>
<tr>
<td>Gas</td>
<td>25,727</td>
</tr>
<tr>
<td>Hydro</td>
<td>80,000</td>
</tr>
<tr>
<td>Nuclear</td>
<td>16,880</td>
</tr>
<tr>
<td>RES</td>
<td>2,75,000</td>
</tr>
<tr>
<td>Total</td>
<td>619,259</td>
</tr>
</tbody>
</table>
EXHIBIT 10(Figures in MW)

Projected Installed Capacity March 2027  (High Hydro)

- **RES**: 275000 (44%)
- **Coal**: 222652 (36%)
- **Gas**: 25727 (4%)
- **Hydro**: 80000 (13%)
- **Nuclear**: 16880 (3%)
To accommodate the variability and uncertainty of generation from RES, the conventional generating plants must be flexible. The flexibility of generating station refers to its ability (i) to cycle on and off including its lead time required; (ii) the ramping rate at which it can vary the generation; and (iii) maximum and minimum output while it is in operation.

The International Energy Agency identifies the system integration costs of renewable energy, consisting of

(1) **Adequacy costs (back-up costs)**  
The variable nature of renewable energy has implications on system adequacy and on the utilization of available power plants. First, in terms of adequacy, generation capacity needs to be present in the system to be able to ensure demand-supply balance at all times, also at times of low RES generation. Second, the variability of RES has implications on how the remainder of the generation system can be operated (shift from base load generation to mid and peak load generation). As such, the variable character of renewable energy causes additional integration costs, referred to as back-up cost.

(2) **Balancing costs**  
On short time scales, the supply-demand balance must be maintained. As the generation from RES is subject to forecast errors, additional operational flexibility might be required in this regard. As such, the partly unpredictable character of RES causes additional integration costs, referred to as balancing costs.

(3) **Grid integration costs**  
Deploying renewable energy requires connecting these to the grid and possibly strengthening the grid (both on the transmission and distribution level), to carry the RES-generated power to load centers. Offshore wind farms require a specific grid connection, while onshore wind and solar PV have a modular nature. As such, these RES cause integration costs, referred to as grid integration costs.
A. Flexible operation

a) Flexible operation of thermal Power Plant

i) Gas based power plants:

The gas-based units have faster response to load changes and higher ramp rates and are thus better suited for flexible operation. However, the Combined Cycle Gas Turbine are designed for base load and have slower response as compared to Open Cycle Gas Turbines. The ramp rate depends on the Turbine and Waste Heat Recovery Boiler designs. The ramp rates are generally in the range of about 3 MW/minute to 10 MW per minute.

For peaking cycles, the operation will be determined by the time, the gas turbine remains under shut down prior to its start of operation. Depending upon the type of machine and start (Hot,warm or cold), startup time may vary from 1 hour to 6 hours. The start-up cost will also depend on the design of machine and source (price) of gas. The estimate of start-up cost is roughly 10-12 lakh per start based on domestic APM gas.

Another aspect that needs to be considered is the impact of start stop on inspection schedules and maintenance. In simplistic terms, number of starts impacts the frequency of scheduled inspections as each start increases the Equivalent Operating Hours (EOH). Increase in EOH with each start is in the range of 10 – 20 hrs for different designs of turbines.

In some of the turbines, number of starts also triggers the inspection. In one case, while the minor inspection is after 24, 000 operating hours (2.7 years), the same is triggered after 450 starts (considering GT is started each day for 1.5 years). Therefore, the inspection schedules are expected to be adversely affected by daily start stop operation in such cases as well.

Moreover, the additional EOH for each start is considered using the turbine in base load mode. The additional EOH for impact of daily start-stop operation and other impacts are difficult to estimate. Taking the case of Dadri CCGT, it has started about 500 times in its 25 years of operation. In evening peaking cycle, this would mean a period of only one and half years. Assessing the impact of such operation is difficult.
Therefore, while in operation units can be suitable for flexible operation to different degrees, suitability for peaking operation will need to be studied on case-to-case basis, especially w.r.t. impact on inspection schedules and the cost of startup.

ii) Coal based power plants:

The start-up time and start-up cost of a coal-based station are relatively higher. Start-up times can be in the range of 3 to 6 hours in case of sub-critical units, whereas for supercritical units, the start-up time can be even higher. Similarly, start-up costs are much higher as compared to gas-based stations (Rs 10-50 lakhs) depending on the type of unit. The O&M costs can also be 50 – 100% higher for cold start-ups as compared to hot start-ups. The hot start-up is 2.5-8 hrs after shut down, warm start is 3-24 hrs and >24 hrs is cold start. However, the criteria for hot/ warm and cold start-up are defined based on HP casing temperature, which varies from unit to unit and design to design.

When coal based capacity is considered for flexible operation, load following cost will also need to be considered. Another aspect that needs to be considered is the operation of super critical units at lower loads which may move the unit into sub-critical range resulting in considerable loss of efficiency.

Comparing the costs:

The following components of cycling costs for thermal power stations (Coal & Gas) needs to be considered:

1. Increase in maintenance, operation (excluding fixed costs), and capital overhaul expenditures
   a. Cost of start-up fuel, auxiliary power, chemicals, and extra manpower for start-ups
   b. Cost of Short-Term Efficiency loss (as already provided in compensation)
2. Cost of heat rate/APC changes due to low load and variable load operation
3. Cost of long-term heat rate increases (a part of which is not restored even after overhauling)
4. Long-term generation capacity cost increases due to unit life shortening
5. Cost of replacement power (DSM) due to increased forced outage. (Associated with EFOR-Equivalent Forced Outage Rates).

The O&M Costs, EFOR Impact, Start-up time for HOT, Warm and Cold starts are all significantly lower in case of Gas-CC. Similarly, for load following the O&M Costs for Typical Ramp rates are also lower in Gas CC.
Higher ramp rates result in higher damage and this is most easily seen on the coal-fired units. While not a linear relationship, study on specific units is required to get further details. The combined cycle units also have a higher ramp rate cost, due to the operational constraints on the HRSG and ST. Emissions requirements (NOx & CO) often limit the ability of a CC unit to load follow below 50% or even 75% for some designs.

Variable Charges due to HR & APC loss at lower loads will increase substantially with the increase in fuel costs. In Gas-CC, it will be significantly higher on liquid fuel. Older combined cycle units were designed for baseload operation and when operated in cycling mode, can have higher cycling costs.

Annexure-1 gives a snapshot of the different costs involved in flexibilisation of units.

A task force under the chairmanship of Director(Operations), NTPC has been constituted to demonstrate the technical and economic feasibility at two power stations of NTPC Ltd. Studies have been conducted at Dadri TPS and Simhadri TPS by VGB, Germany Experts and has recommended the following:

1. Flexible operation of coal unit upto 50% loading can be achieved with minimal investment i.e. 65 lakhs per unit.
2. Flexible operation of coal unit up to 40% loading can be achieved in phased manner with an investment of Rs 7.8 to 17.55 crores per unit.
3. Involvement of OEMs is necessary for implementation of all measures.

ADEQUACY OF BALANCING CAPACITY WITH PROPOSED CAPACITY ADDITION OF COAL AND HYDRO

Studies have been carried out to ascertain the adequacy of balancing and ramping requirement of the Grid with the proposed capacity addition in view of 175,000 MW of RE installed capacity by the year 2022.

While carrying out studies, CEA has considered the demand projections for the year 2021-22 as per the 19th EPS (Energy demand of 1566 BU and Peak Demand of 226 GW), committed capacity addition from Gas 406 MW, Hydro 6,823 MW, Nuclear 3,300 MW, RES 1,17,756 MW during 2017-22 and likely retirement of 22,716 MW of coal based capacity. The studies also assumed that the RE generation is fully absorbed in the system without any curtailment. With the proposed 175 GW of RE by 2021-22, it is estimated that Energy contribution from RE is likely to
be 20% of the total energy requirement. It is observed that due to 175 GW of RES by 2021-22 the frequency of ramping requirement will increase with maximum positive ramping requirement of the order of 24000 MW/hour i.e. 400 MW/min (Exhibit). With the proposed capacity addition, the ramping requirement of 400 MW/min can be achieved if all generating stations exploit their inherent ramping capability and are flexible to operate below 55% (the technical limit as per CERC). As per POSOCO, the system operator, the present daily ramping requirement is of the order of about 250 MW/min and on special days the ramping requirement goes up to 500-600 MW/min which is being managed successfully with present energy mix.

**Exhibit 10**

Studies were also undertaken under the project “Greening the Grid” which is the joint effort of USAID and Ministry of Power, Govt. of India and POSOCO. The studies were aimed to understand the impact of 175 GW of Renewable Energy (RE) by 2022. The studies have been done with the planned generation and transmission capacity. Since the locations of all the new RE which will correspond to 175 GW is yet to be firmed up, the location of the additional new RE has been assumed based on the detailed geospatial weather model by NREL. One National Study and two regional studies (WR &SR) have been done under this project. The National Study ignores the intra state transmission whereas the regional studies consider the detailed model of the concerned region into account including intra state transmission.

Some of the key findings of the National Study are as follows:
1. Annual RE penetration is 22%, with an instantaneous peak of 54% of total demand.

2. Based on existing plans of transmission and Generation, power system balancing with 175 GW RE is achievable at 15-minute operational timescales with minimal RE curtailment.

3. The interstate transmission as planned under Green Energy Corridor is shown to be sufficient for meeting demand requirements as analyzed in this study, but additional intrastate transmission planning should consider project locations of new RE development.

4. The existing flexibility in the coal-dominated power system can handle RE forecast errors, net load changes, and exchanges of energy between regions. System ramps can be met if all generating stations exploit their inherent ramping capability. The ramp rates assumed were a conservative 1% for coal and 3% for gas fired stations.

5. The latent flexibility in hydroelectric generation helps to maintain the system balance.

6. Reducing minimum generation levels of large thermal plants is the biggest driver to reducing RE curtailment. Meeting CERC regulations that require plants to operate at a minimum of 55% rated capacity reduces RE curtailment from 3.5% to 1.4%.

7. Balancing at 15 minute intervals with the coal and gas fleet expected to be in place by 2022 is achievable.

Harnessing flexibility of the combined cycle gas based power plants

All India Gas Generation Installed Capacity at present is 25,185 MW which is around 8% of the total installed capacity and contributes 4% to the total energy generation. The plant load factor (PLF) of gas generation is on declining trend (60% in 2008-09 compared to 22% in 2016-17). This can mainly be attributed to factors such as limited availability of gas etc.

These constraints were studied and it emerged that there is scope for further optimization of gas generation, which is connected to gas grid to provide peaking and balancing support. The domestic gas quantum is limited (only of the order of 13 MSCMD for the gas grid where flexing is supported by the gas infrastructure), at least this capacity can be used for flexing the combined cycle plants. Combined Gas based plants in operation in the country can go down to a minimum 50% capacity, with a ramp rate of 10-12% per minute making it better than coal based plants for flexible operation. However, the heat rate of the combined cycle gas plants reduces at lower load levels as per the graph given below:
Exhibit 11

Thus, it is seen that the heat rate degrades by 12% at 50% loading. There is also wear and tear of plants and consumption of Equivalent Operating Hours (EOH) if the plant is put under shut down and restarted from cold condition when required and also to some extent while ramping up and down frequently. This results in thermal stress in the boiler and turbine and hence loss of EOH. Normally a gas based station has life of 100000 EOH. For every start from cold condition there is loss of 10-20 EOH for a gas based power plant. Therefore, it would be better for gas based stations to be operated at low PLFs to be ramped up and down when required, rather than shutting down the gas power stations, and restarting again, as this will result in higher thermal stress and more loss of EOH.

The plants under the jurisdiction of Regional Load Despatch Centres (RLDCs), aggregating about 3300 MW (excluding 1967 MW RGPPL which supplies to railways currently and would therefore have limited flexibility) have only 4.8 MMSCMD domestic gas allocation which translates to around 1000 MW round the clock generation. Through starts/stops besides operating at minimum load of 55%, these could be at best flex generation between 500-1500 MW required for peaking as well as balancing, instead of 1000MW round the clock. The States can also likewise provide 500-1000 MW by using their combined gas grid connected power plants for peaking and balancing. Some other recommendations such as gas diversion, procurement of additional gas may improve flexible operation of gas based generation in the country to support integration of 175 GW RE by 2022.

Also, the existing gas contracts may need to be modified to include clauses like non-uniform consumption of gas and weekly gas allocation instead of daily with flexibility for less
withdrawal during weekends/holidays/festivals and more on other days keeping the gas consumption for the week as per allocation. This will improve the gas generation for peaking and balancing requirements. A separate committee was also constituted by Ministry of Power to look into this aspect and suggest changes required in gas contracts to improve peak generation.

**Harnessing the flexibility of Hydro power**

The total present installed capacity of hydropower stations is of the order of 44 GW. Storage hydro comprises approximately 25.5 GW while Run-Off-the River (ROR) with pondage comprises of approximately 8.1 GW. Government of India has been assisting the neighboring countries in the development of the hydropower potential for mutual benefits along with harnessing country’s potential of hydropower.

Hydro generating stations are capable of providing fast ramping & peaking support capability and they can be gainfully utilized for regulation services to meet the system requirements. There is a need to provide strong commercial signals that allow flexible resources like hydro to provide peaking capability besides support during high ramp periods besides quick start/stops to take care of intermittency of variable generation from renewables.

Coordinated scheduling and utilization of hydro generation for providing secondary and tertiary frequency control ancillary services, reactive power support through synchronous condenser operation as well as black start services would greatly help in integrating Renewable Energy (RE) generation resources into the grid.
### Typical Flexibilisation costs

<table>
<thead>
<tr>
<th></th>
<th>Up to 200 MW</th>
<th>500 sub critical</th>
<th>Super-critical</th>
<th>Gas cc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Low</td>
<td>High</td>
<td>Median</td>
</tr>
<tr>
<td><strong>Cold Start-up</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M Cost (Rs/MW)</td>
<td>9555</td>
<td>5655</td>
<td>18590</td>
<td>6825</td>
</tr>
<tr>
<td>EFOR(%)</td>
<td>0.0106</td>
<td>0.0085</td>
<td>0.0163</td>
<td>0.0088</td>
</tr>
<tr>
<td><strong>Warm Start-up</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M Cost(Rs/MW)</td>
<td>10205</td>
<td>7280</td>
<td>11765</td>
<td>4225</td>
</tr>
<tr>
<td>EFOR(%)</td>
<td>0.0123</td>
<td>0.0058</td>
<td>0.0156</td>
<td>0.007</td>
</tr>
<tr>
<td><strong>Hot Start-up</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M Cost(Rs/MW)</td>
<td>6110</td>
<td>5135</td>
<td>8515</td>
<td>3835</td>
</tr>
<tr>
<td>EFOR(%)</td>
<td>0.0085%</td>
<td>0.0045%</td>
<td>0.0099%</td>
<td>0.0057%</td>
</tr>
<tr>
<td><strong>Load Following cost (typical ramp rate - %) (Rs/MW) per load following</strong></td>
<td>217.1</td>
<td>124.15</td>
<td>249.6</td>
<td>159.25</td>
</tr>
<tr>
<td><strong>Multiplying Factor - Faster Ramp Rate (1.1 to 2x)</strong></td>
<td>2 to 8</td>
<td>1.5 to 10</td>
<td>1.5 to 10</td>
<td>1.2 to 4</td>
</tr>
</tbody>
</table>

1 USD@INR 65

Costs are based on the data published by M/S Intertek, based on a study of US Utilities. This data is 3-4 years old data and needs to be corrected with inflation. Source: [http://wind.nrel.gov/public/wwis/aptechfinalv2.pdf](http://wind.nrel.gov/public/wwis/aptechfinalv2.pdf)
TOR-4

Road-map to reduce dependence on import of fuel for power generation

Power Utilities are importing coal to bridge the shortfall in the availability of domestic coal as well as to meet the requirement of coal for power generation in the power plants designed on imported coal. In the past, power utilities were advised to import coal to maintain the stipulations of Ministry of Environment and Forest regarding use of coal of less than 34% ash content and to occasionally supplement the coal from indigenous sources. Due to inadequate availability of domestic coal, power utilities were advised to import coal for blending.

The details of coal imported by power utilities to meet the shortfall in the availability of domestic coal and to meet the requirement of power plants designed on imported coal since 2012-13 to 2017-18 (April-Oct) are as under:

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal Imported for Blending (MT)</th>
<th>Coal Imported for Imported Coal based power plants (MT)</th>
<th>Total Import (MT)</th>
<th>% Change in Total Import</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-13</td>
<td>31.6</td>
<td>31.7</td>
<td>63.3</td>
<td>-</td>
</tr>
<tr>
<td>2013-14</td>
<td>37.8</td>
<td>42.2</td>
<td>80.0</td>
<td>26%</td>
</tr>
<tr>
<td>2014-15</td>
<td>48.5</td>
<td>42.7</td>
<td>91.2</td>
<td>14%</td>
</tr>
<tr>
<td>2015-16</td>
<td>37.1</td>
<td>43.5</td>
<td>80.6</td>
<td>-12%</td>
</tr>
<tr>
<td>2016-17</td>
<td>19.8</td>
<td>46.3</td>
<td>66.1</td>
<td>-18%</td>
</tr>
<tr>
<td>2016-17 (Apr-Oct)</td>
<td>13.1</td>
<td>26.9</td>
<td>40.0</td>
<td>-</td>
</tr>
<tr>
<td>2017-18 (Apr-Oct)</td>
<td>9.6</td>
<td>24.0</td>
<td>33.6</td>
<td>-14%</td>
</tr>
</tbody>
</table>

Coal Import by Power Utilities during last 5 years

- Blending (MT)
- Imported Coal based plants (MT)
- Total Import (MT)
1. **Road-Map to reduce dependence on import of COAL for power generation**

Under the guidance of Ministry of Coal, Coal India Ltd. (CIL) has taken initiative for substitution of imported with domestic coal since 2016. Coal India, in this pursuit, has devised customized strategy as per suitability of each power station and has already started the process of substitution of imported coal with domestic coal for many power plants.

i. **Reduce import for blending to zero**

The coal imported for blending during 2016-17 and 2017-18 (April-October) was about 19.8 Million Tonnes (MT) and 9.6 MT. Normally, the grade of coal being imported for blending is about 5400 kCal/kg. Domestic coal of equivalent grade and quantity may be provided to the plants importing coal for blending. This may be safeguarded through enhancement of ACQ and signing of supplementary FSA/MoU.

ii. **Reduce Import for plants designed on Imported Coal**

a. The coal based plants designed on imported coal have imported 46.3 MT and 24.0 MT coal during 2016-17 and 2017-18 (April-October).

b. As per the draft National Electricity Plan, the import of coal required for imported coal based power plants would be around 50 Million Tonnes by 2021-22.

c. As the quality of imported coal is superior to that of domestic coal (less ash content), replacing imported coal to domestic coal may be done keeping in view of the technical feasibility of operation of the plant.

d. Landed price of the imported coal may also be taken into consideration apart from the grade of coal for substitution of the imported coal. The domestic coal equivalent in gross calorific value to imported coal is available with some mines of Eastern Coalfields Limited (ECL) and South-Eastern Coalfields Limited (SECL), which may be used to substitute some part of the imported coal keeping in view other parameters of coal quality.

iii. **Increase in production and availability of domestic coal**

a. The production and availability of domestic coal to power sector needs to be augmented.

b. Environment clearances/Forest clearances/Land acquisition needs to be expedited.

c. CIL has prepared a roadmap to substantially enhance production of coal by 2019-20 to 1 Billion Tonnes by adding capacity from new projects, use of mass production technologies and identification of existing on-going projects with growth potential.
iv. **Better Transportation of domestic coal**
   a. With increase in production of domestic coal, coal needs to be transported to the power plants located at various locations in the country in optimum time. Therefore, Railways need to improve its infrastructure so that sufficient rakes would be available to lift coal from the coal mines/sidings for delivering it to the power plants.
   
b. Coordination between Railways and coal companies to be improved further for making optimum utilization of resources.

2. **Road map to reduce import of NATURAL GAS for power generation**
   i. At present, the country is facing deficit in supply of domestic gas-to-gas based power plants. Due to shortage of gas and as per the requirement of the State, Natural Gas is being imported by gas based power plants. However, due to high price of imported gas (RLNG), cost of generation on RLNG is substantially higher than domestic gas.
   
   ii. The gas based plants have consumed 6.89 MMSCMD (Million Metric Standard Cubic Meter per Day) and 8.71 MMSCMD imported gas during 2016-17 and 2017-18 (April-October).
   
   iii. In order to reduce dependency on imported gas, the availability of domestic gas to power sector needs to be augmented. During 2017-18 (upto Oct,17) averaged domestic gas supply to power plants is around 22 MMSCMD against the total allocation of around 87 MMSCMD.
   
   iv. Gas pipeline infrastructure also needs to be augmented for transportation of natural gas so that gas available at a remote field may be transported to power plants.
   
   v. MOPNG has adopted a multi-pronged strategy to augment gas supplies and bridge the gap between supply and demand for the domestic market. However, the domestic gas supply to power sector is still very low. MOPNG may be impressed upon for additional allocation of natural gas for power sector.
1. **Ultra Supercritical Technology** (steam pressure 280 kg/cm$^2$ and temperature of 600/600 deg C) is also being adopted for recently awarded coal based thermal power plant (Khargone TPP, NTPC in Madhya Pradesh). The improvement in design efficiency of Ultra Supercritical technology is around 1.5% over supercritical units. Many units with conventional supercritical parameters are already operational while number of USC units are under construction.

Deployment of Advanced Ultra Supercritical Technologies (A-USC) having still higher steam parameters 700/800 deg. C for power generation is still in the R&D stage worldwide. A-USC technology demonstration plant is expected to go online around year 2024.

2. **Battery Storage**: Renewable energy deployment in the electricity sector is catalyzing efforts to modernize the electricity grid, including the increased implementation of battery storage. It is understood that variable generation increases the need for flexible generation and operating reserves, which can be met by energy storage by certain extent.

Battery Storage prices are dropping at a much faster pace due to the growing market for consumer electronics and demand for electric vehicles (EVs). The battery-pack costs are down to less than $230 per Kilowatt-hour in 2016, compared to almost 1000 per Kwh in 2010. Major players in Asia, Europe, and the United States are all scaling up lithium-ion manufacturing to serve EV and other power applications.

Currently, solar-plus-storage is not competitive with coal, India’s top energy resource. However, as pressure, builds for environmental restrictions on coal, and with the further reduction in cost due to innovation and technological advancement in the battery costs, experts expect renewable energy to gain an advantage and the battery storage may be a part of the Indian power system in the coming 10 years. Battery storage may start to play a broader role in energy markets, moving from niche uses such as grid balancing to broader ones such as replacing conventional power generators for reliability, providing power-quality services, and supporting renewables integration.
3. **Electric Vehicle:** As per the National Electric Mobility Mission Plan 2012 of Department of Heavy Industries, Government of India, the number of electric vehicles in India is likely to be 6 million by the year 2020 (4 million two wheelers and 2 million four wheelers). Technology and battery advancements are making EVs more attractive to the consumer due to increasing convenience and affordability. EVs have already started to penetrate the market in several Indian cities.

Higher EV penetration will result in an increase in electricity demand however; the demand is not very significant and does not require generation capacity additions as the demand will come during off peak hours. However, the EV may help in utilizing the solar energy during solar peak hours thereby reducing the stress due to the flexible operation. of coal based plants
CONCLUSIONS

1. Mission Statement-

“Aim to achieve Energy Autonomy and provide Clean, affordable, reliable and sustainable power for All”

2. In the base case studies for National Electricity Plan for the period 2017-22, committed capacity addition of Hydro 6,823 MW, Gas 406 MW, Nuclear 3,300 MW, RES 1,17,756 MW (Total RES capacity by 2022 to be 175 GW) has been considered. In addition, a coal based capacity of 22,716 MW is considered for retirement. It was found that only 6,445 MW additional coal based capacity would be required during 2017-22 to meet the peak demand and energy requirement in the year 2021-22 as per the 19th EPS (the CAGR works out to be 6.18% during 2017-22). However, coal based capacity of 47,855 MW is at various stages of construction which is likely to be commissioned during 2017-22. The overall PLF during 2021-22 of coal based capacity (including 47,855MW) is likely to be 56.5%. Therefore, keeping in view the targets for renewable energy generation, efforts in energy efficiency, energy requirement in 2021-22, availability of domestic gas, and existing and under construction power projects, there is not much scope in optimizing the generation mix by the year 2021-22.

3. For the period 2022-27, two scenarios have been carried out to find optimal generation Mix in view of INDC’s Targets and impetus to hydro power development.
   a. SCENERIO-I – INDC Target:

India has announced under INDCs targets that the installed capacity from non fossil fuel should be 40% of the total installed capacity and to reduce emission intensity of its GDP by 33-35% by 2030 from 2005 levels. Results of the studies have shown that the INDC targets can be achieved by having Renewable energy sources installed capacity of 1,25,000 MW by 2027(1,00,000 MW by 2022). Also the carbon intensity considering RES installed capacity of 1,25,000 MW by 2026-27 from the power sector with 1,25000MW RES installed capacity will reduce by 53% by 2027 from the 2005 year. The balancing and peaking requirements in the year 2021-22 and 2026-27 can also be met.
b. SCENERIO-II – Impetus to hydro power

In view of high capacity addition from Renewable energy sources, the problem of providing balancing power and ramping requirement will need to be tackled. However, this can be easily tackled if impetus to Hydropower development is given as these plants can provide balancing power as well as fast ramping rates at minimal cost. Studies have been carried out considering installed capacity of about 80,000 MW (63,301 MW in Base case) assuming that around 50% of the total hydro potential of 148,000 MW by March 2027 is exploited, from hydro power plants (6823 MW during 2017-22 and 28500 MW during 2022-27) along with installed capacity from renewable energy of 2,75,000 MW by 2026-27.

For this scenario, results have shown that coal based capacity will reduce from 2,38,150 MW to 2,22,652 MW by 2026-27 in base case with 2,75,000 GW of RE and Hydro development as Business as usual. This will also result in lower carbon emissions. However, efforts have to be made at war footing to ensure timely harnessing the potential of Hydropower in the country.

4. To accommodate the variability and uncertainty of generation from RES, the conventional generating plants need to be flexible in order to provide balancing and ramping requirement of Grid.

Studies have been carried out by CEA for estimating the adequacy of balancing and ramping requirement in view of proposed RE installed capacity of 175 GW by 2021-22. It is observed that due to 175 GW of RES by 2021-22, the frequency of ramping requirement will increase with maximum positive ramping requirement of the order of 24000 MW/hour i.e. 400 MW/min. With the proposed capacity addition, the ramping requirement of 400 MW/min can be achieved if generating stations exploit their inherent ramping capability and are flexible to operate. As per POSOCO, the system operator, the present daily ramping requirement is of the order of about 250 MW/min and on special days the ramping requirement goes upto 500-600 MW/min which is being managed successfully with present energy mix.

Similar Studies undertaken by POSOCO has also shown that power system balancing with 175 GW Renewable Energy is achievable at 15-minute operational timescales with minimal RE curtailment. Reducing minimum generation levels of large thermal plants is the biggest requirement for reducing RE curtailment.
5. A significant quantum of gas based power plants are under the jurisdiction of State Load Despatch Centres (SLDCs), the scope for flexing combined cycle power plants for flexing would be limited. The plants under the jurisdiction of Regional Load Despatch Centres (RLDCs), aggregating about 3300 MW and with 4.8 MMSCMD domestic gas allocation, could provide peaking as balancing support by way of flexing generation between 500-1500 MW. The States can also likewise use their combined cycle gas based capacity for providing peaking and balancing support. However, the existing gas contracts need to be modified to include clauses like non-uniform consumption of gas etc.

There is a need to provide strong commercial signals that allow flexible resources like hydro to provide peaking capability besides support during high ramp periods besides quick start/stops to take care of intermittency of variable generation from renewables.

Coordinated scheduling and utilization of hydro generation for providing secondary and tertiary frequency control ancillary services would greatly help in integrating Renewable Energy (RE) generation resources into the grid.

6. In order to reduce dependence on import of fuel for power generation, following needs to done:

   i. Coordination between Railways and coal companies to be improved further for making optimum utilization of resources. This may be done through a transparent web portal indicating information about the coal at each mines, transportation by railways and stock at power plants.

   ii. The production and availability of domestic coal to power sector needs to be augmented.

   iii. Environment clearances/Forest clearances/Land acquisition needs to be expedited.

   iv. CIL has prepared a roadmap to substantially enhance production of coal by 2019-20 to 1 Billion Tonnes.

   v. Gas pipeline infrastructure also needs to be augmented for transportation of natural gas so that gas available at a remote field may be transported to power plants.
vi. MOPNG may be impressed upon to allocate additional Natural gas to power sector for better utilization of gas based power plants in view of high RE integration.

7. Introduction of new technologies like ultra-supercritical technologies can improve efficiency of coal based power generation by 1.5% over supercritical units. Battery storage and Electric vehicles technologies are under Research and Development. With reduction in cost, these technologies can play an important role in providing Grid Stability, reduction in Environment emissions and also can shift generation or load as necessary to fill the gap between RE generation and demand.
ANNEXURE- A

No-33/12/2017-R&R (Part-2)
Government of India
Ministry of Power
Shram Shakti Bhawan, Rafi Marg,
New Delhi, 27th October, 2017

ORDER

Subject: Constitution of a Committee to give recommendations on the optimal energy mix in power generation on medium and long-term basis-reg.

In the Brain Storming Session chaired by Hon’ble Minister of State (I/C) for Power and Renewable Energy with officers of Ministry of Power (MoP) and MNRE on 9.10.17, it has been decided, inter-alia, to constitute a Committee to give recommendations on the optimal energy mix in power generation on medium and long-term basis. Accordingly, a Committee is hereby constituted with the following composition:

i) Chairperson (CEA) -Chairman
ii) Joint Secretary (Thermal), MOP -Member
iii) CMD, NTPC -Member
iv) CMD, NHPC -Member
v) Representative from MNRE -Member
vi) Representative from NITI Aayog -Member
vii) Representative from Tamil Nadu -Member
viii) Representative from Uttar Pradesh -Member
ix) Representative from Maharashtra -Member
x) Chief Engineer (OM, R&R), MOP - Convener

2. The Committee may co-opt experts (any other member) as may be considered necessary.

3. The terms of reference (ToR) of this Committee are as follows:

   i) Formulate the mission statement for aiming at energy autonomy, clean, affordable, reliable and sustainable power for all;
   ii) Year-wise, fuel wise optimal generation mix in the next 15 year time horizon taking into account India’s Nationally Determined Contributions (NDCs) under the Paris Climate Agreement, economic growth, environmental concerns, grid security and adaptability to the changing technology landscape in the power sector.;
iii) Recommend the optimal balancing requirement required in the grid and
develop scenarios for integration of renewable at various energy-mix levels including
respective cost of integration;
iv) Suggest the road map to reduce the dependence on import of fuel for power
generation;
v) The base line of the study would be the present existing scenario. Committee
should factor in the environmental concerns, Grid security and adaptability to the
changing Technology in power sector;
vii) Any other issues to achieve objectives of the mission statement.

The Committee shall submit its report within one month from the date of its constitution to
the Ministry of Power

(Sandeep Naik)
Director
Tele: 2371 5250

To
1. Secretary, MNRE, CGO Complex, New Delhi. (with a request to nominate a senior
person conversant with the subject)
2. Chairperson, CEA, New Delhi
3. CEO, NITI Aayog, New Delhi
4. Principal Secretary (Energy), Govt of Tamil Nadu
5. Principal Secretary (Energy), Govt of Uttar Pradesh
6. Principal Secretary (Energy), Govt of Maharashtra
7. CMD, NTPC.
8. CMD, NHPC.

Copy to: Joint Secretary (Thermal), Chief Engineer (OM, R&R), MoP.

Copy for information to:
1. PS to MoS(I/C) MoP.
2. PPS to Secretary (Power), PPS to AS(R&R), PPS to CE(R&R), PS to
   Dir(R&R), MoP.
ANNEXURE-B

Minutes of the 1st meeting of the Committee on the optimal Energy mix in power generation on medium and long term basis under chairmanship of chairperson, CEA, held on 7/11/2017 at 5pm in CEA.

List of participants is at Annex-1

1. The 1st meeting of the committee was held under the chairmanship of Shri Ravindra Kumar Verma, Chairperson, CEA on 7/11/2017 in CEA. The committee was constituted by the Ministry of Power to give recommendations on the optimal energy mix in power generation on medium and long-term basis. The constitution of the committee and the terms of reference is at Annex -2.

2. Chief Engineer (OM, R&R), MoP gave a brief background about the constitution of the Committee and the Terms of Reference. Chairperson, CEA gave a perspective on the issues involved in the planning and the futuristic vision that need to be deliberated.

3. Chief Engineer (IRP), CEA and Director, IRP, CEA gave a brief presentation on the planning exercises that has been done for National Electricity Plan (NEP). The assumptions and its findings were discussed in light of the ToR given to the committee.

4. Joint Secretary (Thermal), MOP gave his perspective and suggested that the Committee should confine itself to the technical recommendations best suited to the Indian condition.

5. Based on the detailed deliberation following decisions were taken:-

   (1) A visionary mission statement to be formulated by the committee.

   (2) Economic analysis to be done for use of gas-based power station vs Coal based power station for flexible operation to meet the balancing requirement due to large-scale renewable integration. Can low cost Coal based generation substitute the high cost gas based generation for meeting flexibility requirement? What would be the environmental impact for such substitution?

      (Action: All members, NTPC to coordinate)

   (3) As the INDC target is to be met by Year 2030, realistic exercise is to be done for staggering of the capacity addition under Renewable Energy Source (RES), so that we are able to meet the INDC targets and cause less imbalance for conventional sources. This is required, as with the present target of RES capacity addition by 2022, the RES installed capacity would by
37% and in terms of Energy, it would be 21% of the total Energy generated in the country. However, it would stress the generation capacity under conventional energy sources and in particular, the coal based power stations, as the average PLF is expected to be as low as 56.5%.

(Action: All members, MNRE to coordinate)

(4) Impact of some of new technology e.g. battery storage, Electric vehicle, Ultra Super critical technology were briefly discussed. These need to be considered in the long-term scenario say during 2022-27.

(Action: All members, Niti Aayog /MNRE to Coordinate)

(5) The Committee decided to Co-opt following members.

(i) Member (Planning), CEA.

(ii) CEO, POSOCO.

(iii) CE (IRP), CEA.

(iv) CE (FM), CEA.

(v) CE (TETD), CEA.

(vi) Mr Saurabh Didi, BEE.

(vii) A representation from CERC

CE (IRP) would coordinate with all members of the Committee and collate the inputs given by them. He would be assisted by one officer from NTPC in preparation of the Report of the Committee.

(6) The Committee was of the view that seeing the gestation period of conventional generation and the power projects already in pipeline along with existing generation mix, there is little scope for optimization of generation mix up to 2022. However, the aggressive RE target of 175 GW by 2022, which is also likely to cause concerns of requirement of balancing power and other operational issues, can be moderated to some extent keeping INDC target in view. However, there is scope of optimization in the time horizon of 2022-27. All committee members were requested to give their suggestions.

(7) In spite of having huge installed capacity at present, there have been instances of less availability of the generation capacities in the grid. Thus, grid is stressed due to non-availabilities of operational capacity. Say this year the contingencies were failure of monsoon, less generation from Hydro, wind and nuclear, shortage of coal, etc. Some time, even capacities are there but these are idle and do not support the grid at the time of need.

To deal with such operational issues in planning, the following were suggested;
i. Identification of peaking capacities.

ii. Identification of balancing capacities.

iii. Regulatory intervention, if required, in terms of pricing signal or running of idle capacities, if required, due to technical reasons. Presently the generating stations are running mostly on commercial basis.

iv. Views of POSOCO need to be taken in this.

(Action: All members, POSOCO to give inputs & coordinate)

(8) One of the suggestion for peaking power was, Whether, We can have differential fixed cost (say high during peak hour and low during off peak hours)?

(Action: All members, CERC to give input)

(9) Committee to work out the actual cost of generation for RES which inter-alia would include balancing cost, transmission charge waiver impact etc.

(10) Chairperson requested all members to give their independent views irrespective of the organization that they belong to, on each issues listed in the ToR and send the same to CE (OM, R&R) MoP and CE (IRP), CEA by 15/11/17.

(Action: All members, CE (IRP) to collate and bring out the base paper for deliberation in the 2nd meeting).

(11) 2nd meeting of the committee may be held in 3rd week of November, 2017.

Meeting ended with thanks to chair.
# Annexure 1

## LIST OF PARTICIPANTS

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<tr>
<th>Sl.No.</th>
<th>Name/designation</th>
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