

# **User Guide for India's 2047 Energy Calculator**

## **Municipal Waste to Energy**

## Sector Handbook: Municipal Waste to Energy

### 1. Overview of the sector/Introduction/ Trends and historic growth

As per Census 2011, 377 million people, that is, 31.2% of the total population in India live in towns. Number of towns increased from 5161 in 2001 to 7935 in 2011. 42.6% of this urban population resides in metropolitan cities. Further, it is expected that more than 50% of India's population will reside in urban areas by 2050.

One of the attributes of large agglomeration of people in urban areas is waste generation that is beyond the assimilative capacity of the local ecosystem, and hence requires careful management. Municipal Solid Waste (MSW), which gets generated primarily by households and commercial establishments, is heterogeneous mix of combustibles, organic matter, inert materials and moisture. Urban India produces about 1.5 lakh metric tonnes per day (MTPD) of MSW at present. About 81% of total MSW is generated in 468 Class-I cities (cities with a population of more than one million). Waste collection efficiency ranges between 70% and 90% in major metro cities, and in several smaller cities, it is less than 50%.

Effective management of MSW is based on the 3-R principle – Reduce, Recycle and Recover (Fig 1 represents hierarchy of MSE management). Reduced waste generation at source and recycling are generally most cost-effective ways of waste disposal.

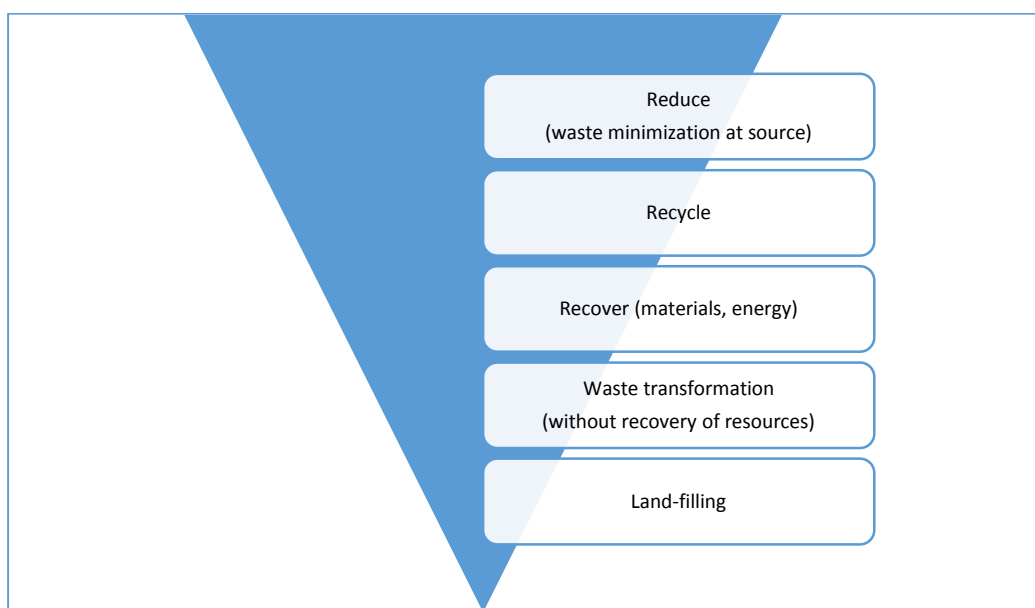


Fig 1: Routes for solid waste management in order of preference

Treatment and processing of MSW is almost absent in most cities except composting and refuse-derived fuel (RDF) in a limited manner. Most MSW is dumped in landfills adding to the land and water pollution. However, with changing economic status and lifestyles, and resultant quantity and composition of MSW, energy recovery could well prove to be a key strategy to dispose MSW components that are most amenable to recovery of energy. For example, the organic fraction of the

MSW contains bio-degradable matter ranging from 30% to 55%, which can be converted into compost, refuse-derived fuel or energy (WTE) products.

Energy generation from waste can be through biochemical conversion or combustion, depending on various aspects such as the levels of segregation, collection efficiency of MSW and others.

While technologies for WTE are existent and in use for several decades in many countries, and first experiments were held in India in last quarter of 20<sup>th</sup> century, WTE sector can still be considered in its initial stages in India and the viability of technologies, process and projects, is still being established.

A major initiative that provided required impetus toward MSW management for large cities is Jawaharlal Nehru Urban Renewal Mission (JNNURM), which envisages the components like primary and secondary collection, transfer station, transportation, integrated solid waste management facility with composting, RDF & sanitary landfills for MSW management. In parallel, there have been central government sponsored programmes for small and medium cities. However, despite significant funding being made available by Central Government to states and local bodies under the programs, the progress is slow. The focus of urban bodies has been on removing garbage (read MSW) from the houses and streets, and MSW segregation, and processing have taken back seats.

For same reasons, so far, there has been limited focus on recovering waste from energy, with India's installed capacity on waste to energy (urban and industrial) being only around 154 MW as on March 2015. All this capacity has been developed on mixed waste and incineration/ combustion / biodegradation of waste is carried out after its processing at the energy recovery site, which is certainly less optimal than segregating MSW at source.

## 2. Existing legal/regulatory policy frameworks

As per the Constitution of India, solid waste management is a state subject. State legislation and the local laws governing municipal authorities include provisions for collection, transportation, and disposal of waste. According to these legislations, urban local bodies (ULBs) or the municipal authorities must provide these services.

At the central level, The Ministry of Urban Development (MoUD), Government of India, is the nodal agency that formulates policies and strategies on various aspects of urban development including solid waste management and also provides technical and financial assistance to the states. The Central Public Health and Environmental Engineering Organisation (CPHEEO) is the technical wing of MoUD. Ministry of New and Renewable Energy (MNRE) leads the development of waste to energy sector and hence expected to collaborate closely with MoUD/CPHEEO as well as state level stakeholders.

Without appropriate legislation and any associated monitoring mechanisms on the performance of municipalities, the system of waste management remained inefficient. Consequently, in response to a public interest litigation filed in 1996, the Supreme Court of India, in 1999, directed the Government of India, state governments, and municipal authorities to deliver effectively on management of solid waste in the country. The Ministry of Environment and Forests (MoEF) was directed to issue rules for MSW management and handling.

In the year 2000, the MoEF notified the Municipal Solid Waste (Management and Handling) Rules 2000, under the Environment Protection Act 1986. These rules mention steps to be taken by all municipal authorities to ensure management of solid waste as per best practice. Municipal authorities

are required to meet the deadlines stated in Schedule I of the rules and must adhere to the compliance criteria and procedure mentioned in Schedule II. Implementation level guidelines were published in 2000 as 'Manual on Municipal Solid Waste Management and Handling 2000' by MoUD through CPHEEO.

The MSW Management and Handling Rules 2000 require the municipal authorities to obtain clearance from the state pollution control board (SPCB) to set up waste processing and disposal facilities. The SPCBs are directed to process the application of municipal authorities and to provide clearance to the municipalities within 45 days of the submission of the application.

The Central Pollution Control Board (CPCB) is responsible for coordinating the implementation of the rules among the state boards. The municipalities were mandated to implement the rules by December 2003, with punishment for non-compliance. However, most municipalities did not meet the deadline. Central and state governments are facilitating, through financial support and other means, provision of MSW management services for ULBs, and the coming years will thus see more progress.

### 3. Drivers

India's daily per capita solid waste generation is one of the lowest in the world – 0.2 to 0.6 kg/capita/day. This is because the consumption patterns have been low till now and recycling rates are inherently high in the country. This is a positive factor when it comes to solid waste management. Waste minimization, recycling, and traditional methods like composting are cost-effective ways of waste management. However, with rapid urbanization, MSW generation is increasing and waste composition has enhanced quantity of substances amenable only to energy recovery e.g. food packaging, sanitary napkins etc.

To effectively process, manage and dispose of such waste, it is essential that we segregate waste at generation points. Improved segregation and collection practices will also help recover energy in a cost-effective manner because this is a critical parameter for successful operation of all the existing waste to energy conversion technologies, which are otherwise well-proven, economically viable and have been performing well in other countries. At the same time, pollution control technologies have also become more efficient, which otherwise has been a major constraint for waste recovery technologies in last few decades.

Effective waste management can provide alternative fuels that can be used in a variety of ways. For instance, refuse-derived fuel (RDF) can be used to generate electricity. It can also replace traditional fuels used in facilities such as cement kilns and thermal power plants. Converting MSW into biogas can provide clean cooking fuel to rural areas, thereby reducing our dependence on hydrocarbons. Thus, energy recovery from MSW will diversify to our energy basket.

However, in India, presently, segregated waste collection efficiency is nearly 0%. This is a major barrier to widespread deployment of conversion technologies mentioned above. Additionally, issues in maintaining a consistent supply chain of the feedstock for the conversion plants have delayed scale. We envisage that segregation at source, mandated by the MSW (Management & Handling) Rules, 2000, is expected to improve over the coming years. Waste management is also a key focus area under the Jawaharlal Nehru National Urban Renewal Mission launched in 2005, and more recently with the Swachh Bharat Abhiyaan, launched by the Honourable Prime Minister of India, in October 2014.

#### 4. Assumptions

IESS 2047 assumes the following to build the supply trajectories for the municipal WTE sector:

- a. Waste generation, collection efficiency, segregation efficiency and waste composition are considered same across all four levels. The envisaged MSW composition is given below:

Table 1: Existing and projected composition of MSW

S.No.	Organic/ compostables (food waste) (%)	Combustibles (paper, wood, plastics, rags, cloth, leather, rubber) (%)	Recyclables/inorganic (metals, ceramics, glass) (%)	Others (dust, ash, fines, inert) (%)
2012	40	10	5	45
2047	44	26	9	21

- b. Waste composition will have enhancing levels of organic waste (slow growth), combustibles (fast growth), and recyclable materials (medium growth) while contribution of inert matter will keep decreasing.
- c. No significant waste to energy capacity additions will take place during the 12<sup>th</sup> plan
- d. Beginning 13<sup>th</sup> plan, increasing quantities of waste will be channelized to generating energy as well as electricity.
- e. Urban areas
- Waste generation will reach 750 g per capita in 2047 compared to 370 g per capita in 2012
  - Collection efficiency will reach 100% by 2047 from an average of around 70% in 2012
  - Segregation efficiency will reach 90% in 2047 compared to 0% in 2012
- f. Rural areas
- Per capita rural MSW generation will be less than that in urban areas
  - For purpose of energy recovery, even under the best scenario, only organic fraction of rural MSW will be available because of sparse population density
  - Daily rural per capita organic waste generation is assumed to be half of that of its urban counterpart at 325 g per capita in 2047 as compared to 75 g per capita in 2012
  - Collection efficiency will reach 100% by 2047
  - Segregation efficiency will reach close to 70% in 2047 compared to 0% in 2012

Table 2: Technology parameters for conversion routes

Bio-chemical conversion		Thermo-chemical conversion	
Total Solids (TS) (%)	15	NCV of segregated combustibles (kCal/kg)	3600
Total Volatile Solids (% of TS)	78	Typical conversion efficiency (%)	25
Typical digestion efficiency for urban systems (%)		1 KW (equivalent kCal/hr)	860
Urban systems	60	NCV of non-segregated waste (kCal/kg)	2400
Rural systems	45		
Typical bio-gas yield (m <sup>3</sup> / kg of VS destroyed)	0.6		
Calorific value of bio-gas (typical) (kcal/m <sup>3</sup> )	5000		

## 5. Methodology

IESS 2047 shows four levels for development of municipal waste to energy, over 2012-2047 for urban as well as rural areas of India. The MSW generation rates and change in its characteristics across the years are based on estimated growth rate of India's urban and rural population and also comparing the same with that of other developing as well as developed countries.

Technologies considered for modelling the scenarios are:

- Biogas Generation through bio-methanation
- Power Generation through thermo-chemical conversion using especially designed combustion systems
- Combined Heat and Power (CHP)

## 6. Scenarios

**Level 1** assumes that there will be no capacity additions and hence MSW based waste-to-energy capacity will remain at a level of 96MW. There will be no capacity additions even beyond 2017, primarily due to lack of inter-agency coordination and favourable policies. Other key adverse factor will be limited understanding of technical issues involved in construction, operational and environmental aspects of MSW based waste-to-energy projects. Once these projects have lived their life, there will be no MSW based waste-to-energy projects, by 2037.

**Level 2** assumes that the capacity addition happen in line with 12th plan targets resulting in 153MW installed capacity by end of 12th Plan. Most of it will still be based on mixed MSW. With improving segregation levels and Government's focus on waste-to-energy, by 2047:

- 25% of segregated urban organic MSW will yield 0.36 MTOE of biogas
- 20% of segregated rural organic MSW will yield 0.28 MTOE of biogas
- 18% of total 'waste to electricity generation' potential will be realized resulting in approx 3,550MW installed power generation capacity
- 18% of segregated urban combustibles will be used as fuel yielding 2.36 MTOE of thermal energy

**Level 3** assumes that Government and ULBs emphasize on MSW based waste-to-energy as a key resource recovery option. The policies and incentives get aligned. Rural areas adopt organic MSW based gas as a key energy option. However in urban areas, evolving technologies like combined heat and power still does not get any traction. By 2047:

- 50% of segregated urban organic MSW will yield 0.72 MTOE of biogas
- 40% of segregated rural organic MSW will yield 0.55 MTOE of biogas
- 30% of total 'waste to electricity generation' potential will be realized resulting in approx 5,850 MW installed power generation capacity
- 32% of segregated urban combustibles will be used as fuel yielding 4.4 MTOE of thermal energy

**Level 4** assumes that there are absolutely no barriers (economic, social or technical) to the growth of MSW based waste-to-energy. Inter-agency conflicts are also resolved. Waste-to-energy sector gets enhanced attention coupled with significant increases in fossil fuel prices, especially coal.

Fossil fuel externalities are priced. Energy security is consciously factored in energy planning. In this level, by 2047:

- 75% of segregated urban organic MSW will yield 1.09 MTOE of biogas
- 60% of segregated rural organic MSW will yield 0.83 MTOE of biogas
- 30% of total 'waste to electricity generation' potential will be realized resulting in approx 5,850MW installed power generation capacity
- 63% of segregated urban combustibles will be used as fuel yielding 8.44 MTOE of thermal energy
- 30% of combustible urban waste will be used for combined heat and power applications yielding 4.35 MTOE of energy

## 7. Costs

For building the cost trajectories, three types of applications have been considered:

- Biogas generation
- Mixed waste to power
- Segregated waste to power

CHP has not been accounted for in the cost estimates because there is no CHP plant in India that is currently operational.

Inputs were sought from experts, practitioners and technology providers to arrive at possible trends in capital costs for the applications specified above.

### Assumptions

Cost trajectories assume the following:

- I. Waste collection and segregation costs are not loaded to energy generation facility since the associated costs would anyways have to be incurred for effective solid waste management
- II. Waste processing costs are included in the estimated capital, operation and maintenance costs
- III. Calorific value of segregated waste and mixed waste is assumed to be 3600 kCal/kg and 2400 kCal/kg respectively, beyond 2017
- IV. Operations and maintenance expenses (as a percentage of capital expenditure) have been assumed as:
  - 8% (segregated waste to power)
  - 10% (mixed waste to power)
  - ~5% (biogas generation)

## 8. Tables- Scenarios (High, low, point)

### Biogas generation

Table 3: Capital cost per TPD for new capacity (INR Crore)

Year	2012	2017	2022	2027	2032	2037	2042	2047
High Estimate	0.29	0.28	0.28	0.28	0.27	0.27	0.27	0.27
L1	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25
L2	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25
L3	0.29	0.27	0.26	0.24	0.23	0.22	0.21	0.20
L4	0.29	0.27	0.25	0.23	0.21	0.20	0.18	0.17
Low Estimate	0.29	0.26	0.24	0.22	0.20	0.19	0.17	0.16

Table 4: Annual operation and maintenance cost per TPD for new capacity (INR Crore)

Year	2012	2017	2022	2027	2032	2037	2042	2047
High Estimate	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
L1	0.011	0.011	0.011	0.011	0.011	0.010	0.010	0.010
L2	0.011	0.011	0.011	0.011	0.011	0.010	0.010	0.010
L3	0.011	0.011	0.010	0.010	0.009	0.009	0.008	0.008
L4	0.011	0.011	0.010	0.009	0.009	0.008	0.007	0.007
Low Estimate	0.011	0.010	0.010	0.009	0.008	0.008	0.007	0.006

**Power generation (through mixed MSW)**

Table 5: Capital cost per MW for new capacity (INR Crore)

Year	2012	2017	2022	2027	2032	2037	2042	2047
High Estimate	21.0	20.8	20.6	20.4	20.2	20.0	19.8	19.6
L1	21.0	20.6	20.2	19.8	19.4	19.0	18.6	18.2
L2	21.0	20.6	20.2	19.8	19.4	19.0	18.6	18.2
L3	21.0	20.0	19.0	18.0	17.1	16.2	15.4	14.7
L4	21.0	19.5	18.2	16.9	15.7	14.6	13.6	12.6
Low Estimate	21.0	19.3	17.8	16.4	15.0	13.8	12.7	11.7

Table 6: Annual operation and maintenance cost per MW for new capacity (INR Crore)

Year	2012	2017	2022	2027	2032	2037	2042	2047
High Estimate	2.10	2.08	2.06	2.04	2.02	2.00	1.98	1.96
L1	2.10	2.06	2.02	1.98	1.94	1.90	1.86	1.82
L2	2.10	2.06	2.02	1.98	1.94	1.90	1.86	1.82
L3	2.10	2.00	1.90	1.80	1.71	1.62	1.54	1.47
L4	2.10	1.95	1.82	1.69	1.57	1.46	1.36	1.26
Low Estimate	2.10	1.93	1.78	1.64	1.50	1.38	1.27	1.17

**Power generation (through segregated MSW)**

Table 7: Capital cost per MW for new capacity (INR Crore)

Year	2012	2017	2022	2027	2032	2037	2042	2047
High Estimate	17.0	16.8	16.7	16.5	16.3	16.2	16.0	15.8
L1	17.0	16.7	16.3	16.0	15.7	15.4	15.1	14.8
L2	17.0	16.7	16.3	16.0	15.7	15.4	15.1	14.8



L3	17.0	16.3	15.7	15.0	14.4	13.9	13.3	12.8
L4	17.0	16.0	15.0	14.1	13.3	12.5	11.7	11.0
Low Estimate	17.0	15.6	14.4	13.2	12.2	11.2	10.3	9.5

Table 8: Annual operation and maintenance cost per MW for new capacity (INR Crore)

Year	2012	2017	2022	2027	2032	2037	2042	2047
High Estimate	1.36	1.35	1.33	1.32	1.31	1.29	1.28	1.27
L1	1.36	1.33	1.31	1.28	1.25	1.23	1.20	1.18
L2	1.36	1.33	1.31	1.28	1.25	1.23	1.20	1.18
L3	1.36	1.31	1.25	1.20	1.16	1.11	1.06	1.02
L4	1.36	1.28	1.20	1.13	1.06	1.00	0.94	0.88
Low Estimate	1.36	1.25	1.15	1.06	0.97	0.90	0.82	0.76

## 9. Key Messages

Waste management is a key priority for the government and effective waste management needs to incorporate all possible options, including waste to energy. Swachh Bharat Abhiyan and the proposed waste-to-energy Mission are steps in the right direction towards effective waste management.

However, any waste to energy efforts must build on the three principles of Reuse, recycle and recovery – in the same priority. It means that energy recovery should always be after maximum possible reuse and recycling has been achieved.

The characteristics of urban waste are fast changing and enhanced quantities of waste in future would have to be managed by the energy recovery route. Hence waste to energy is a critical priority. Lack of it would lead to unmanaged waste. Energy output from MSW may not be very high. However, it will be a lost opportunity and would have huge carbon implications (due to methane generation from unprocessed waste) if not attended properly. At the same time, from the energy security and climate change perspective, Waste to energy is important considering that the resource (waste) is free and lead to reduces GHG emissions.

## 10. Graphs, tables and charts

Fig 2: Biogas Generation

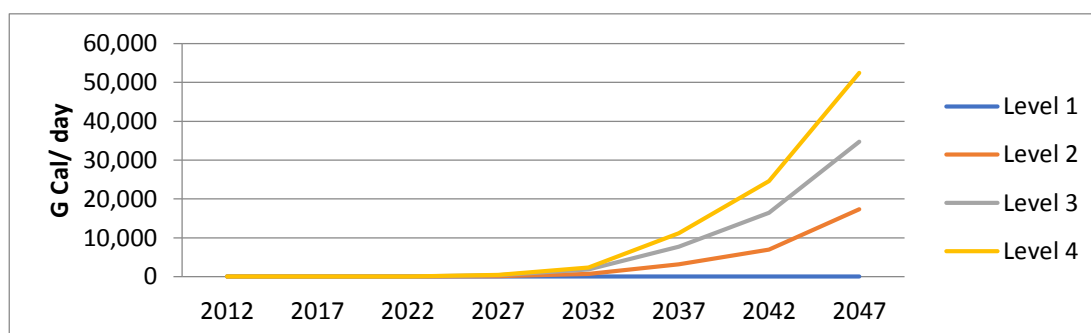


Fig 3: Fuel Availability

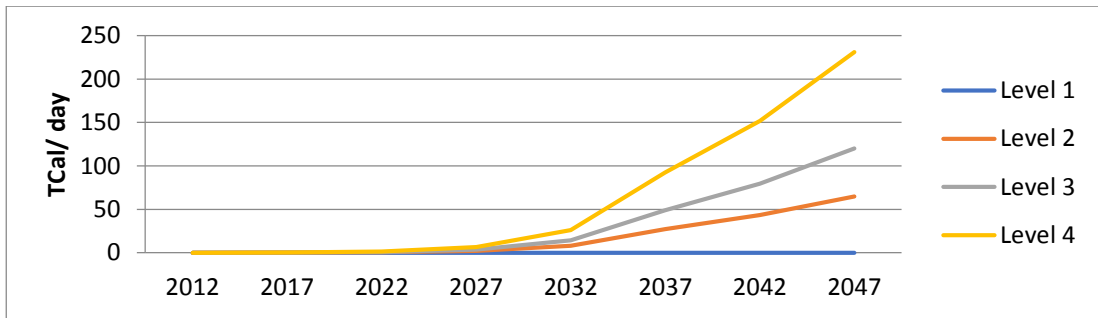
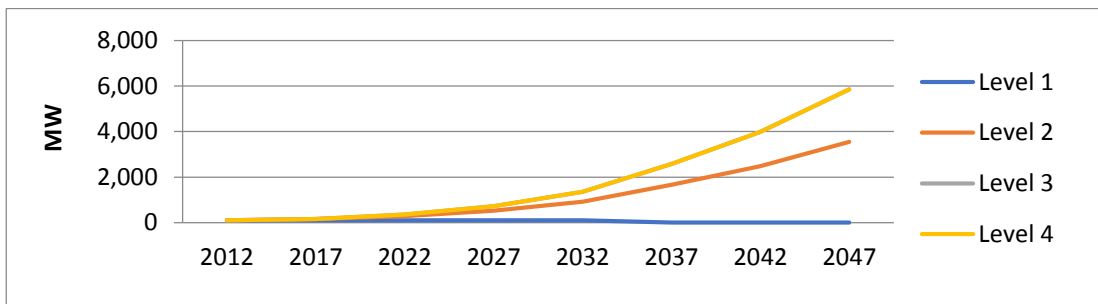


Fig 4: Waste to Power Capacity



## Costs

### I. Biogas generation

Fig 5: Capital cost per TPD of new capacity

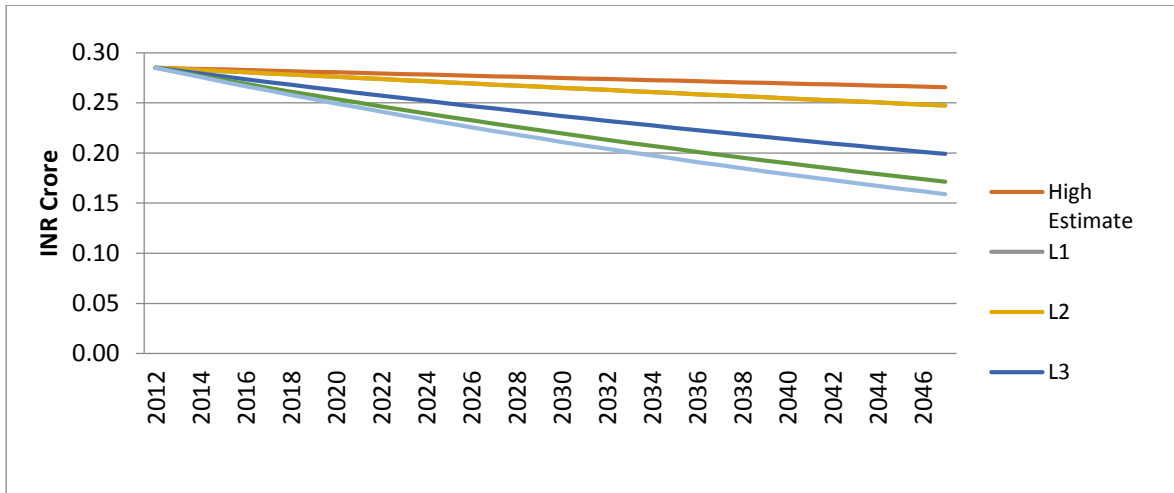
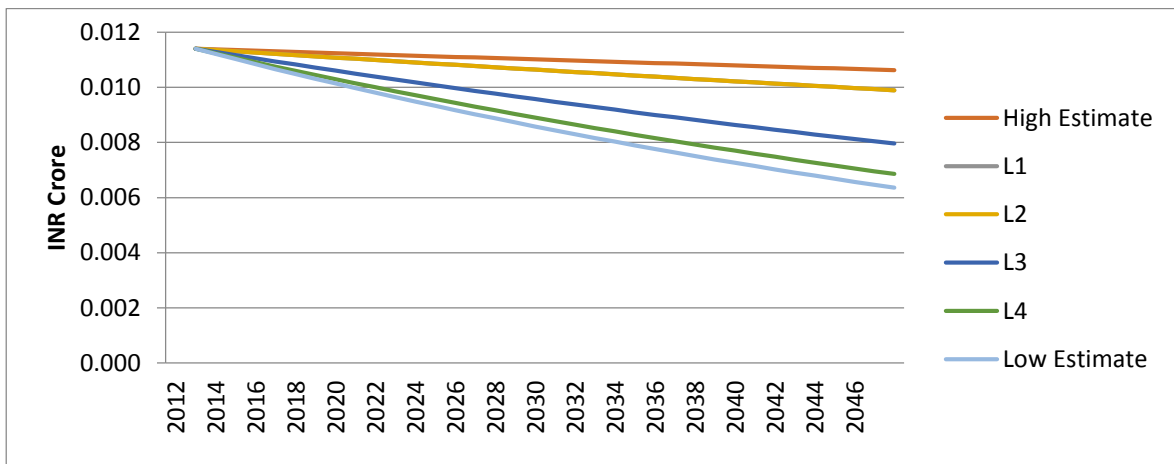


Fig 6: Annual O&M cost per TPD of new capacity



### II. Power generation through mixed MSW

Fig 7: Capital cost per MW of new capacity

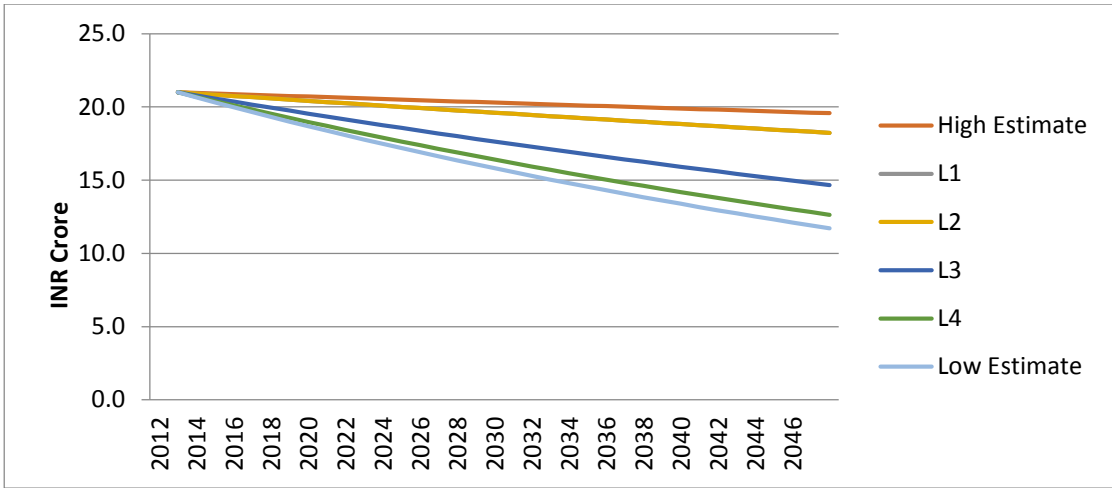
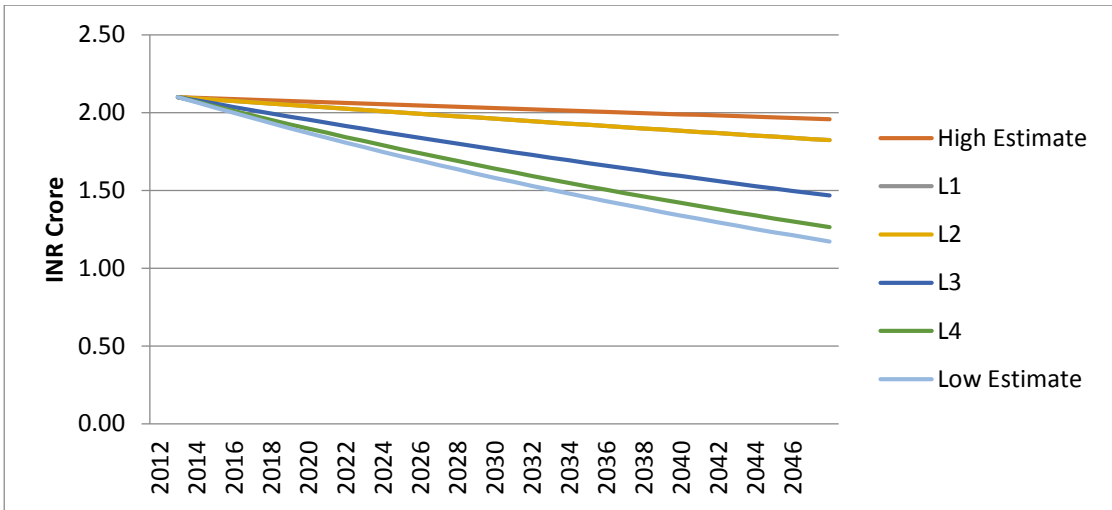


Fig 8: Annual O&M cost per MW of new capacity



III. Power generation through segregated MSW

Fig 9: Capital cost per MW of new capacity

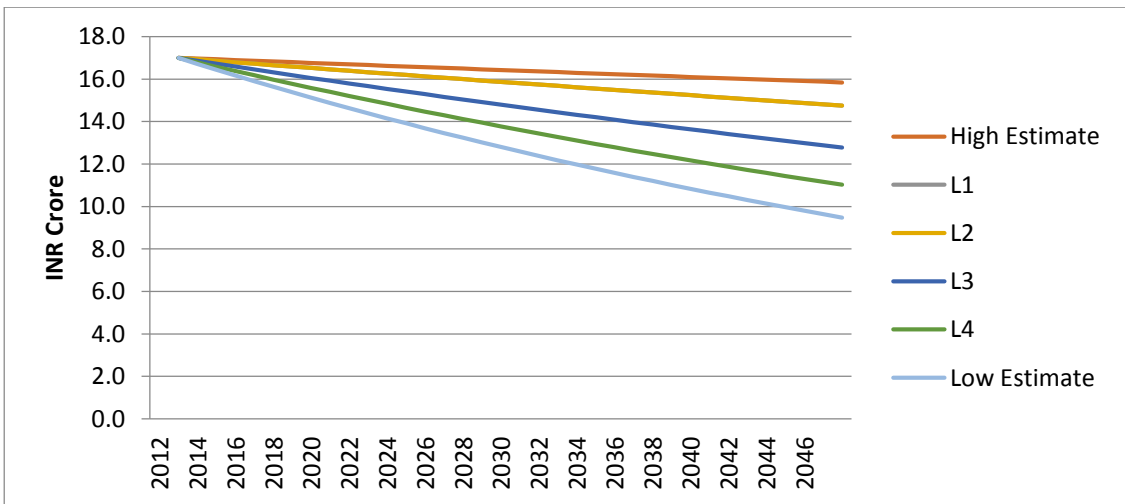
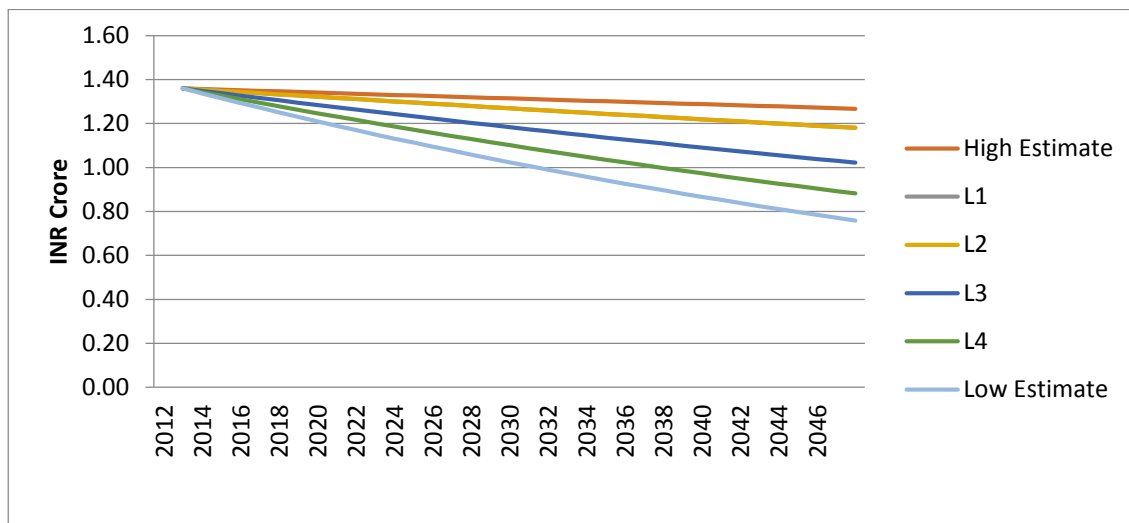


Fig 10: Annual O&M cost per MW of new capacity



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