Long-Term Evolution of Building Energy Demand for India: Disaggregating end use energy services in an integrated assessment modeling framework

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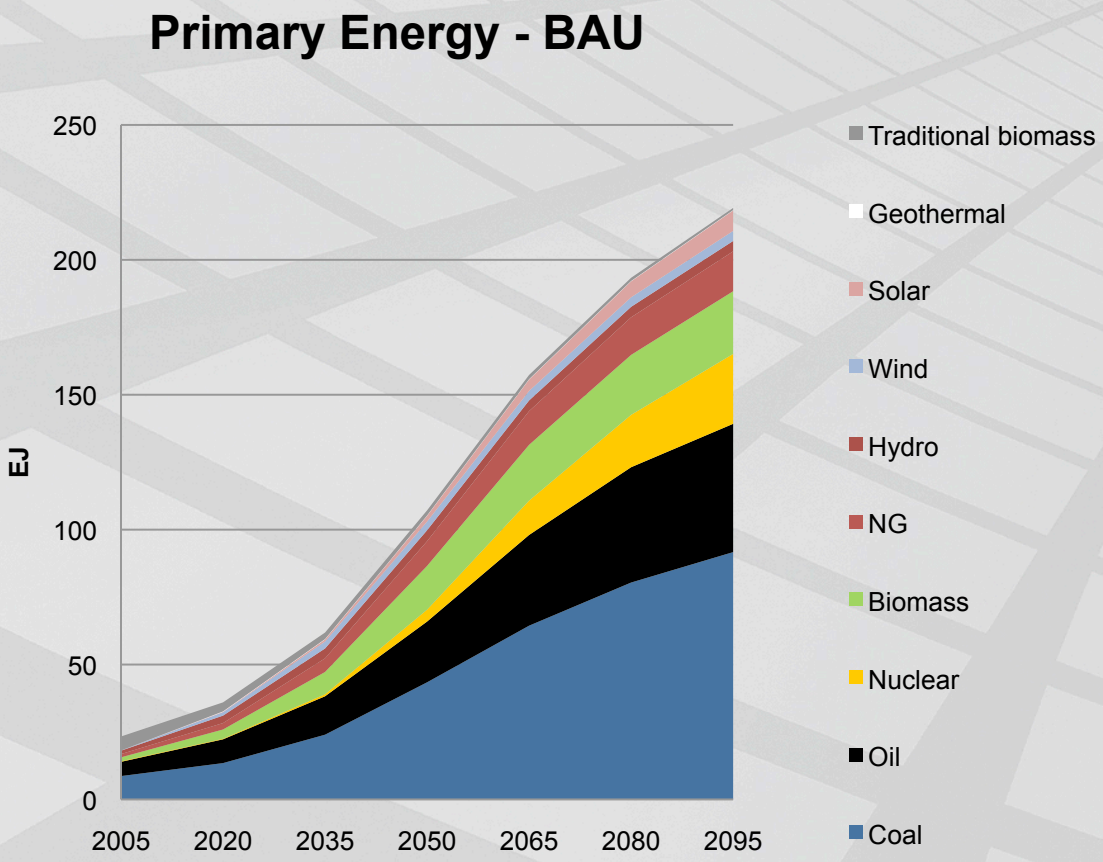
Background

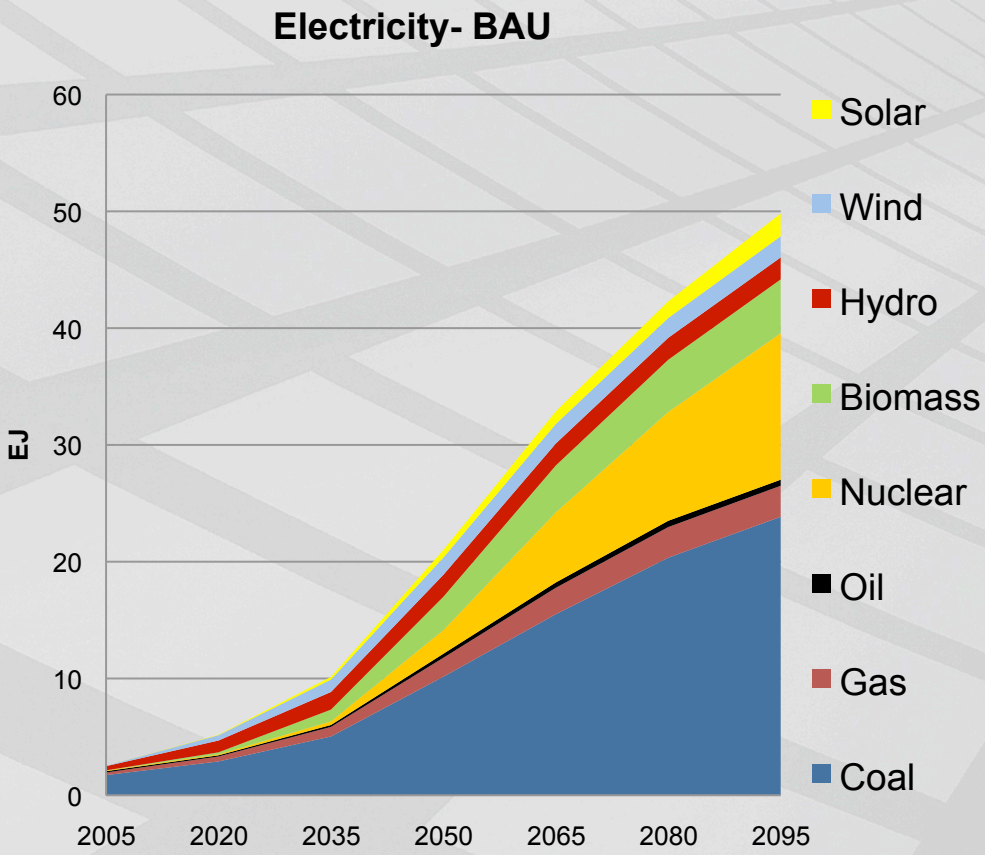
- High economic growth expected for India, more than 8-9% in the near future
- Population more than 1.2 Bn
- Rapid urbanization
- Managing energy demand and ensuring adequate and reliable energy supply important challenges for Indian policy

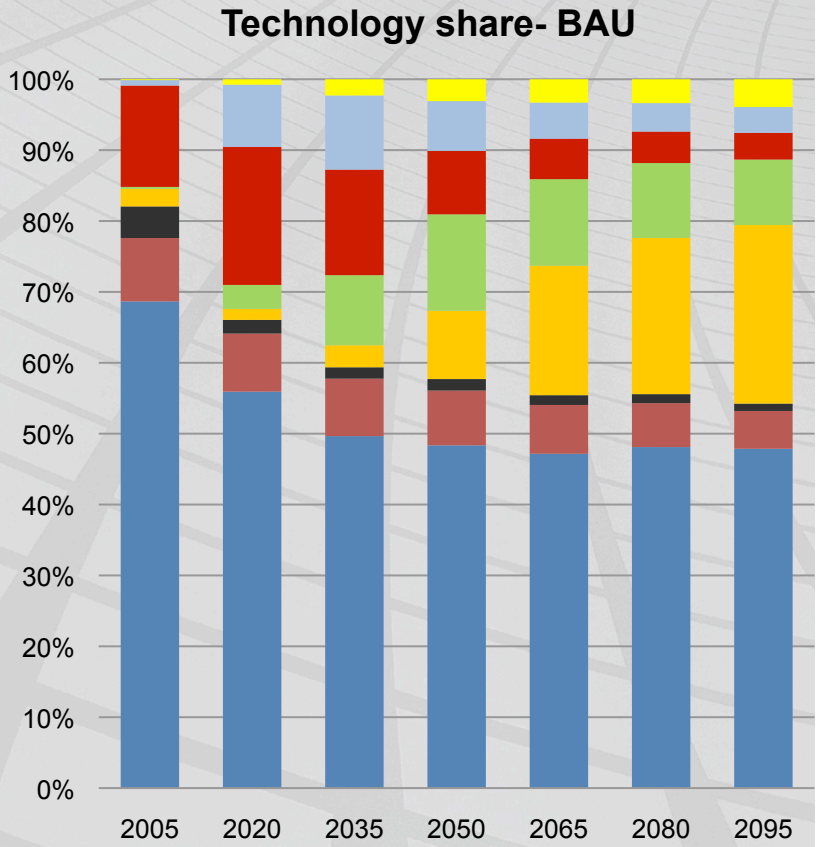
Primary Energy



- Coal and oil take highest share throughout BAU
- Increasing penetration of biomass and nuclear
- Low share of non-biomass renewable

Electricity sector





Modeling Building Energy Use:

Moving from Supply to Demand

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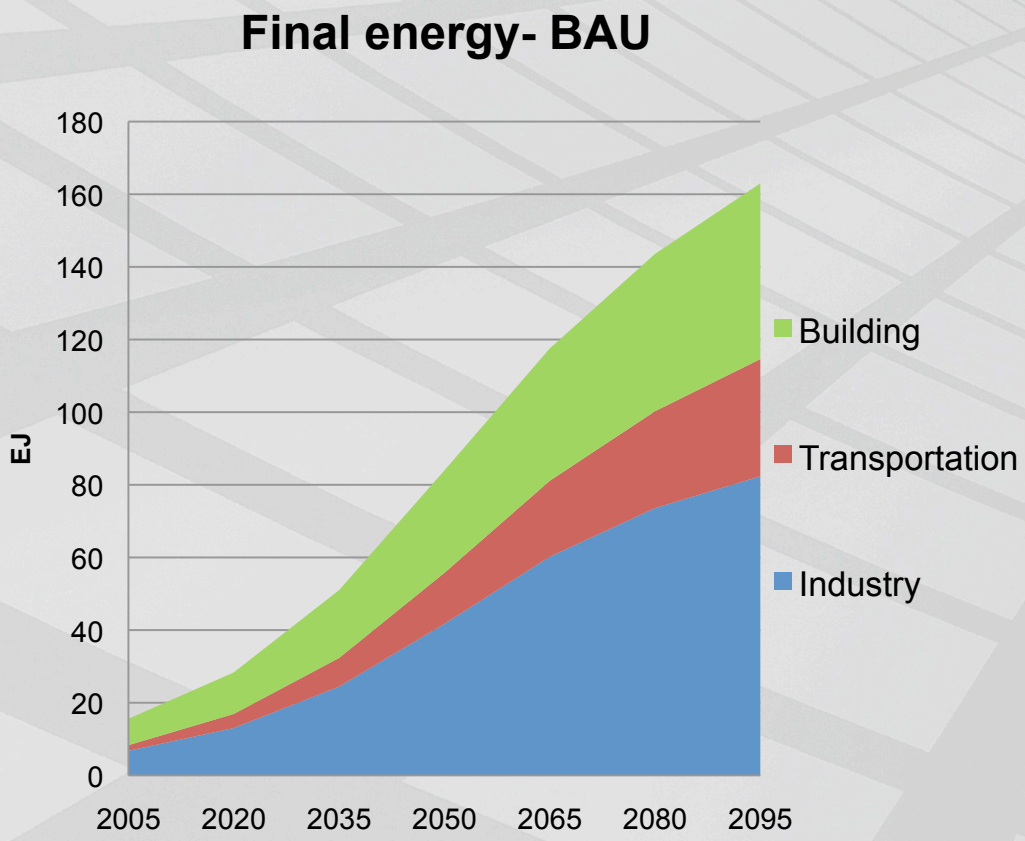
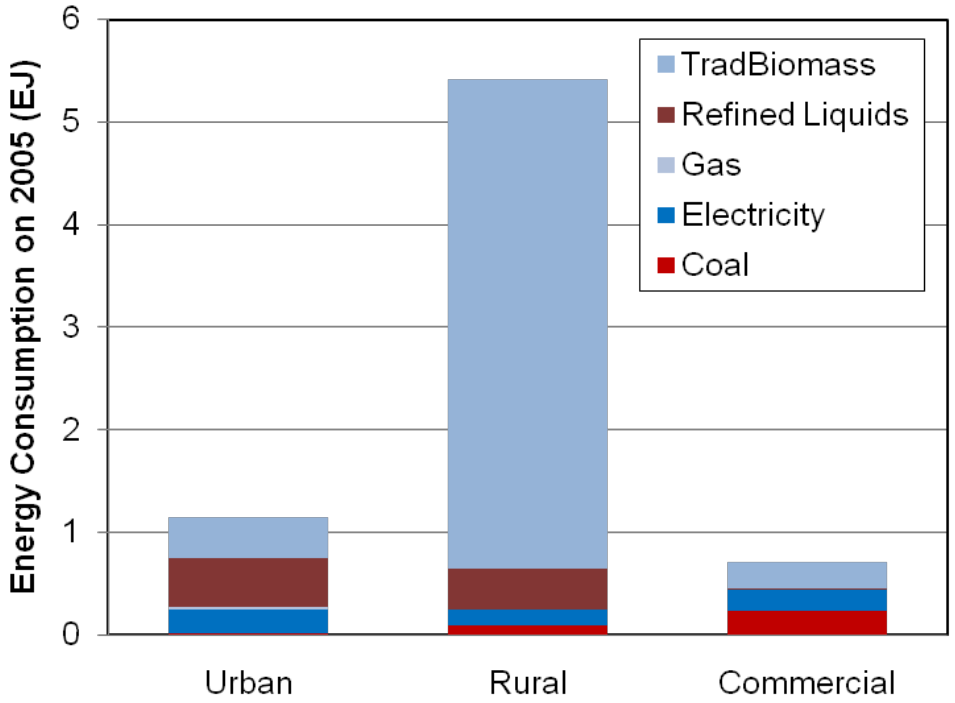
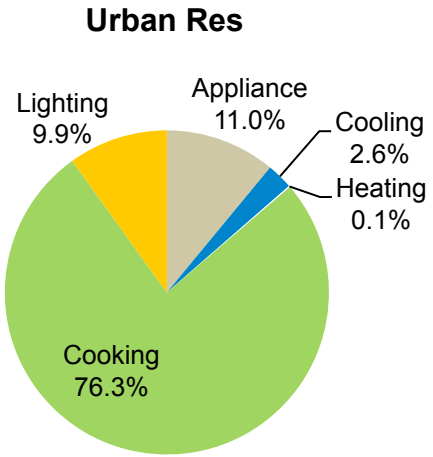
Building energy consumption in India

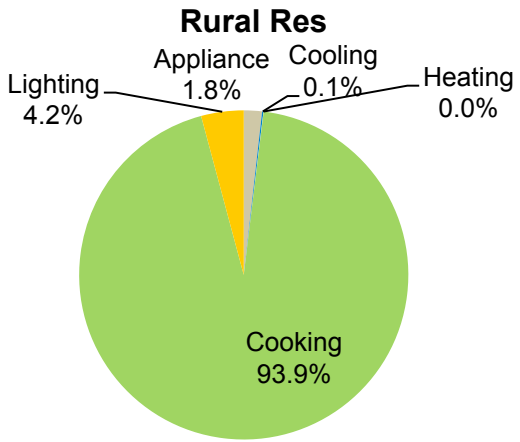


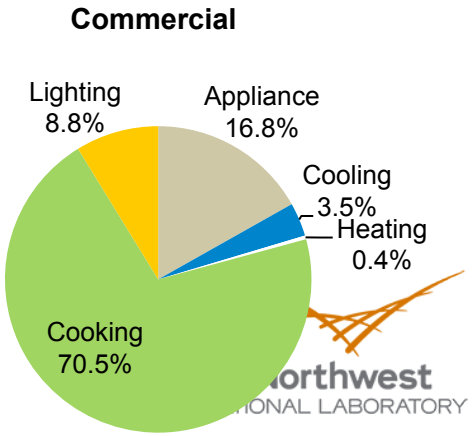
- More than 45% of total final energy in India consumed in the building sector
- This share expected to decrease in the future
- High reliance on traditional biomass
- Significant difference in rural and urban energy consumption profiles

India Buildings' Energy Consumption (2005)





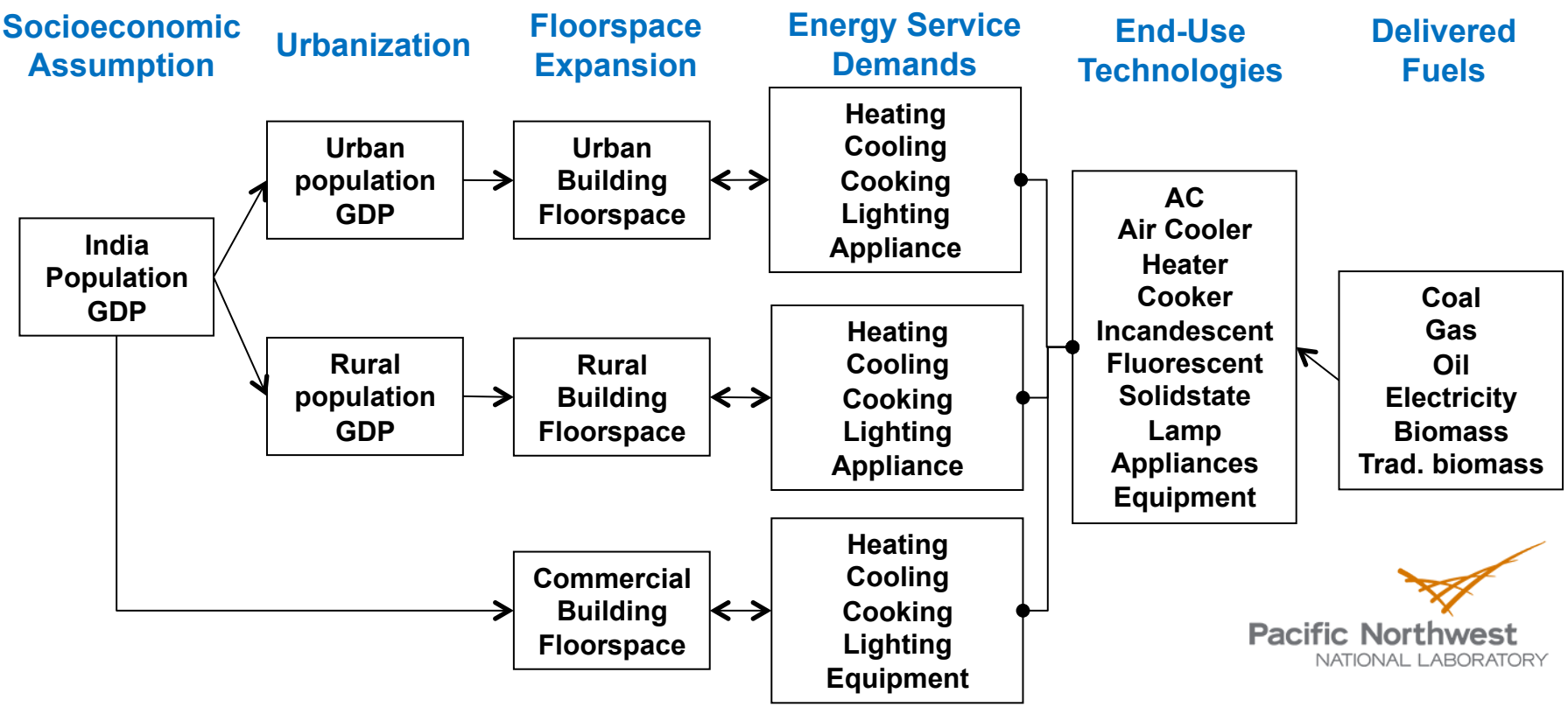




The Detailed Model for Building Energy Use in India

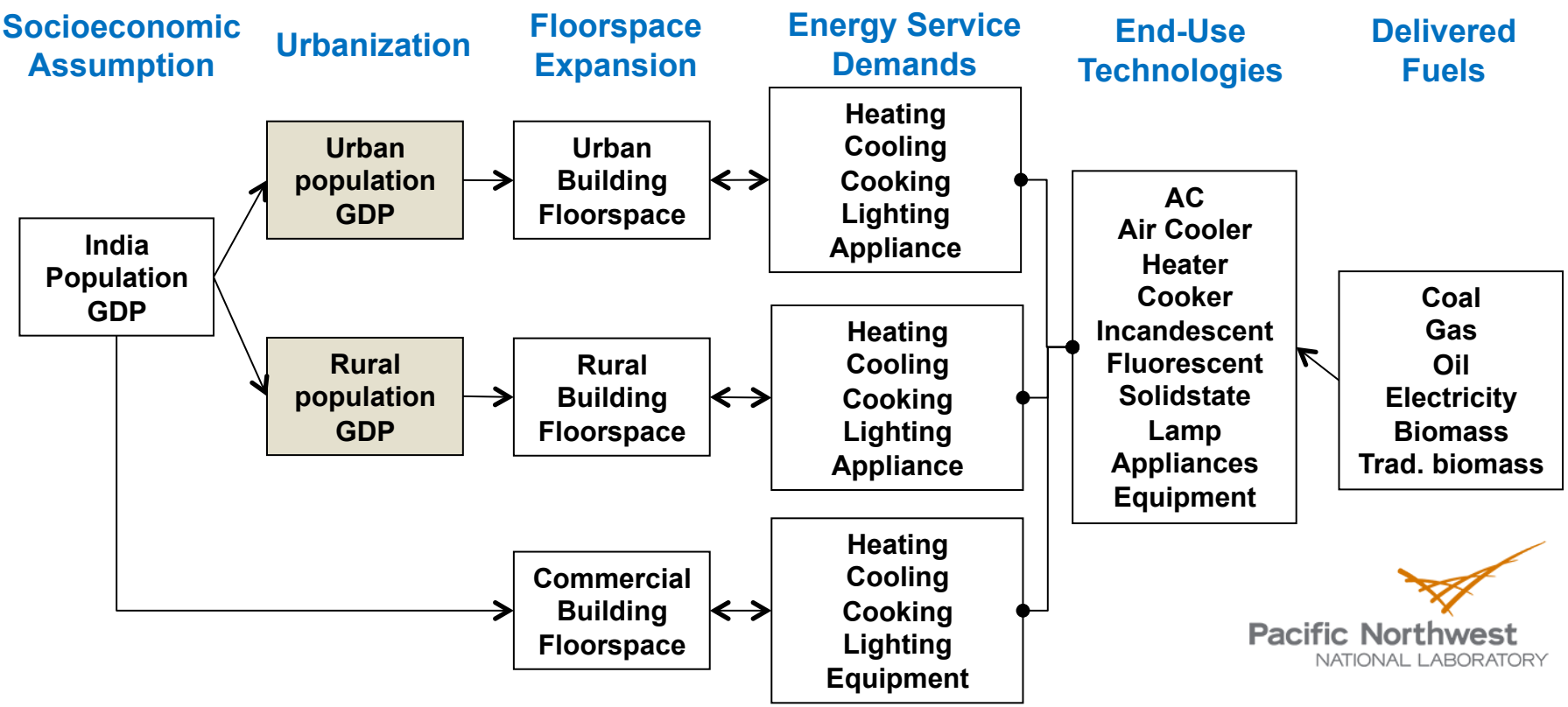
- Model framework based on Eom et al. (2011)

- Has been applied earlier to model China building energy demand



Modeling Challenges

1. How should urban/rural population change over time?



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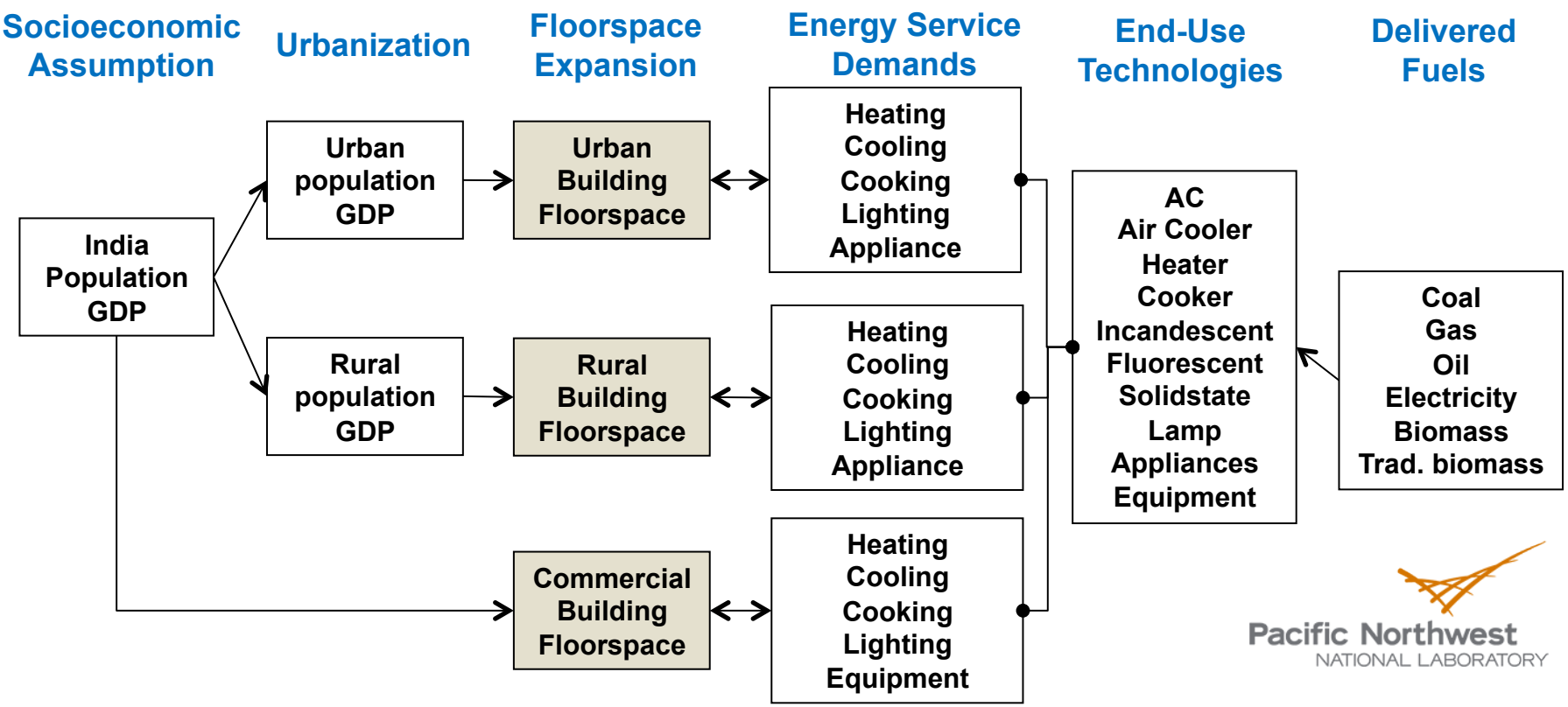
Modeling Challenges

1. How should urban/rural population change over time?

2. How to build a reasonable floor space expansion model?

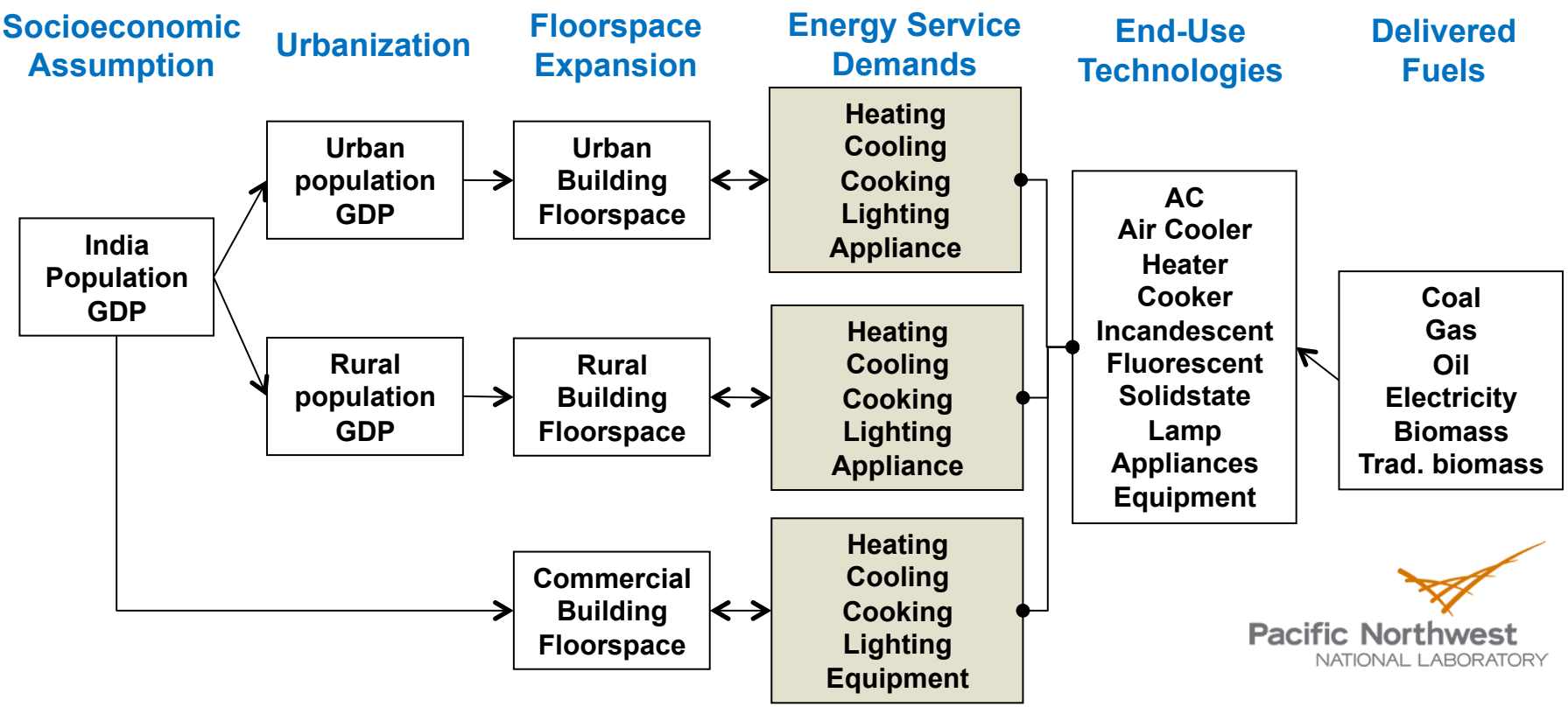


Modeling Challenges

1. How should urban/rural population change over time?

2. How to build a reasonable floor space expansion model?

3a. How should energy service demands per unit of floor space vary with income and prices?



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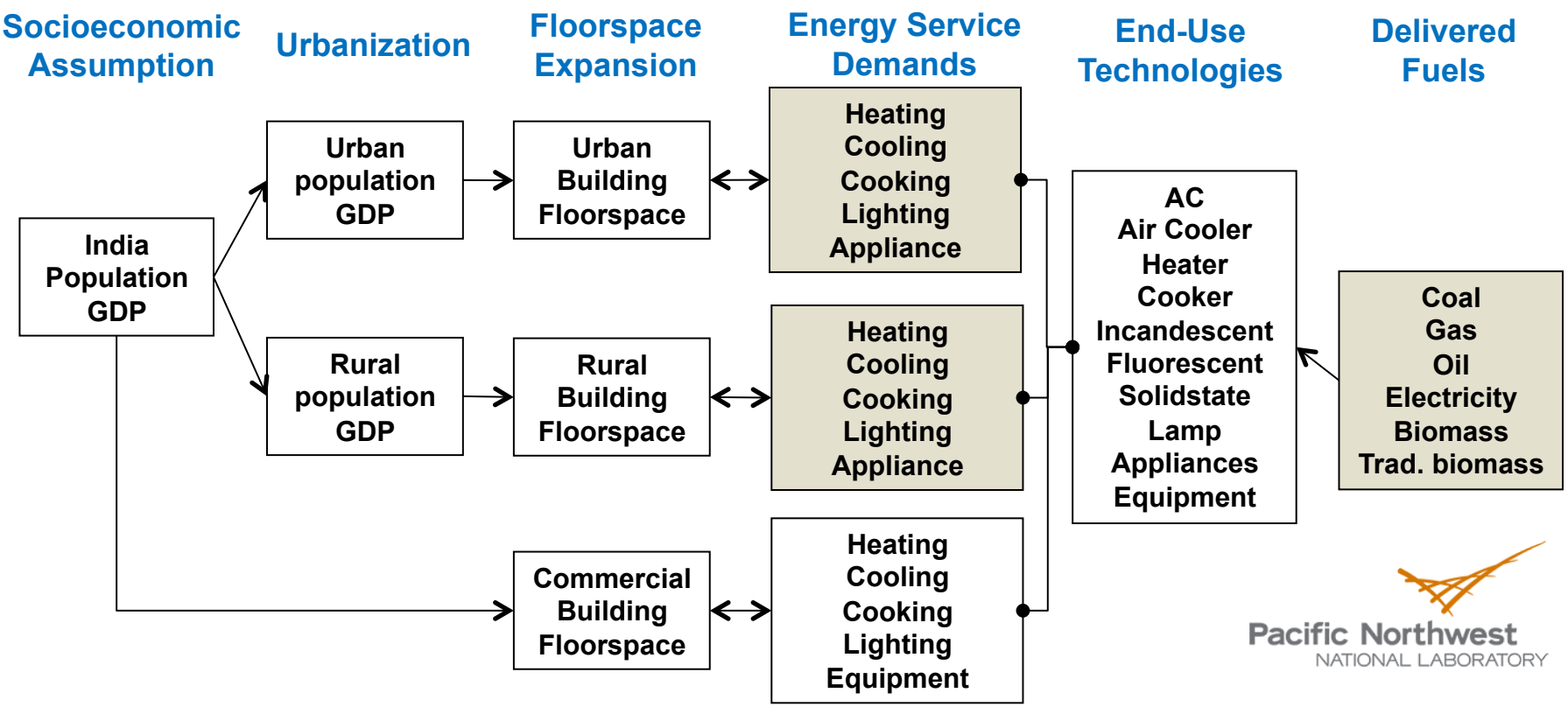
Modeling Challenges

1. How should urban/rural population change over time?

2. How to build a reasonable floor space expansion model?

3a. How should energy service demands per unit of floor space vary with income and prices?

3b. How to define urban/rural preferences for individual energy service demands and fuels?



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Urbanization in India

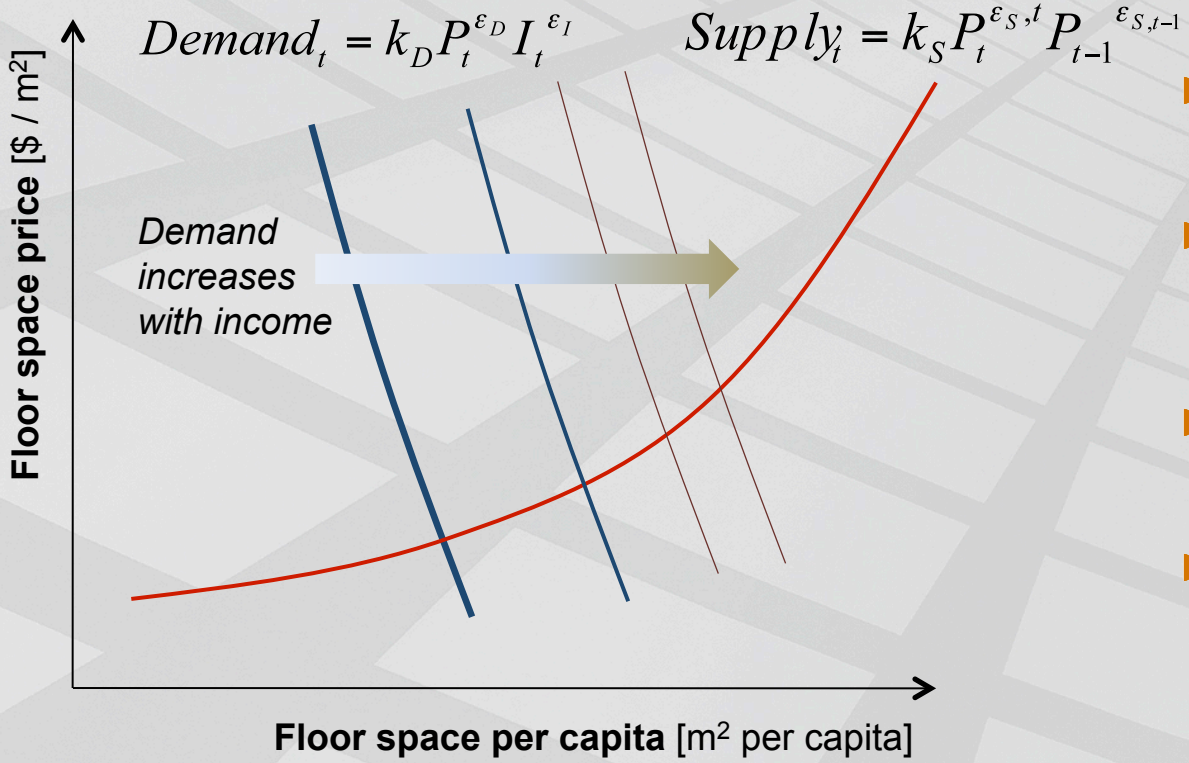
- **We specify a relationship between urbanization rate and total income**

  Based on parameters obtained by regressing data from national statistics and UN urbanization prospect (by 2050)

- **Urbanization mostly occurring between 2005-2050 and ultimately reaching 70% in India by the end of the century**

- **Income gap narrowing between rural and urban areas**

The approach to Floor Space Expansion



This is a very idealized approach that has some weaknesses when applied to floorspace.

- Urban / rural/commercial floor space expansion is not inter-related.
- Households' preferences for floor space depends only on where they are currently located.
- There is no noticeable lag in market adjustment to price and income changes.
- Steady decline in household size is not an important factor.

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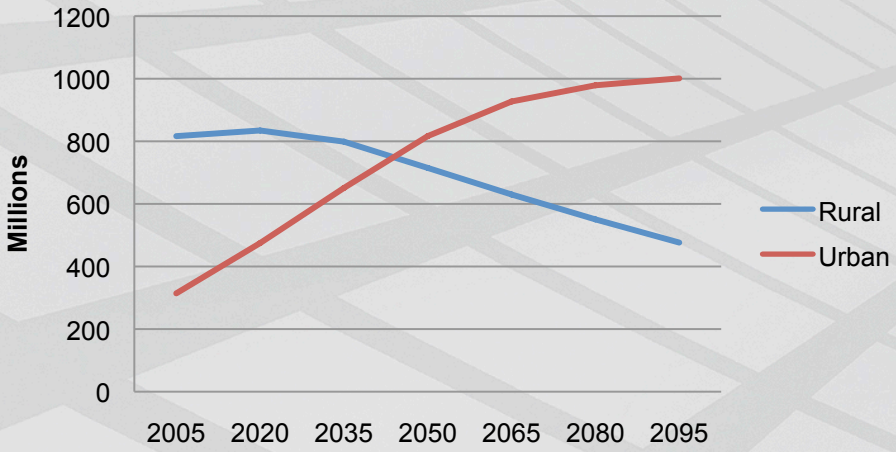
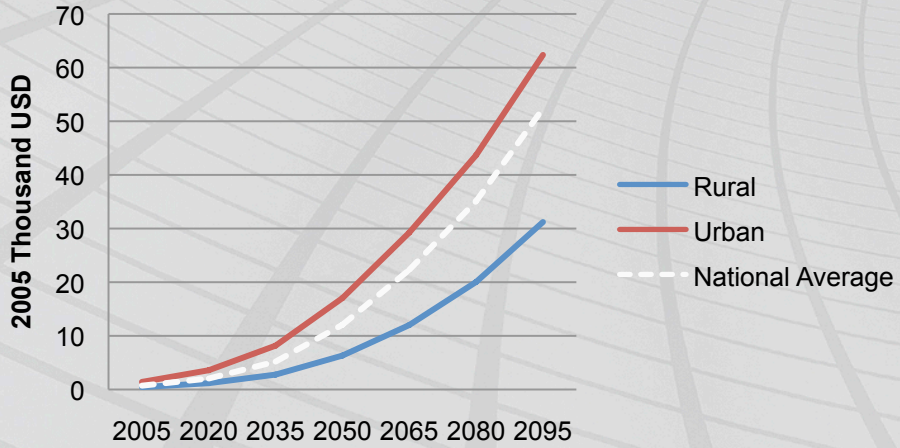
Drivers of energy consumption

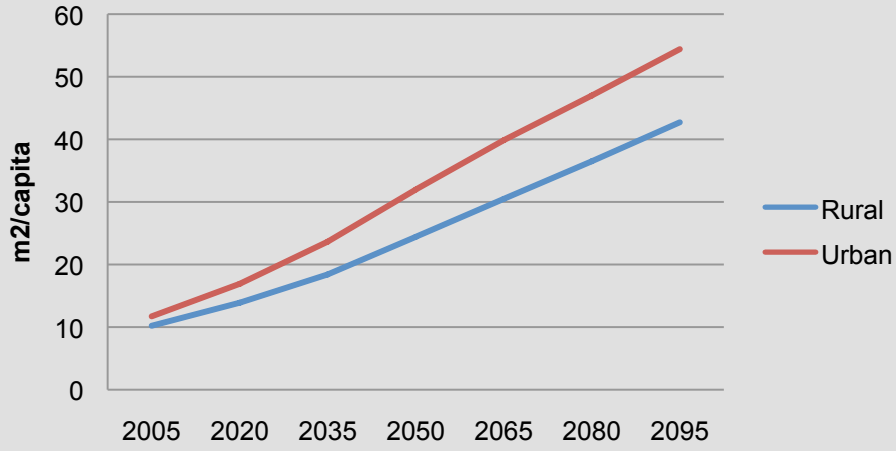
Population



Per capita income



Per capita floorspace



Increasing population in urban areas to drive floor space and energy service demands

Per capita income gap assumed to converge by 2200

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Demand for Building Services

Modeling the Change in Service Demands

Demand for Space Heating Service [GJ-output/m²] :

$$Q_{H,t} = k_H \cdot \left(HDD_t \cdot ShellEff \cdot SurfaceRatio_t - \lambda_H InternalGain_t\right) \cdot \left[1 - \exp\left(-\frac{\ln 2}{\alpha_H} \cdot \left(\frac{Y_t}{P_{H,t}}\right)\right)\right]$$

Space Heating Requirement (satiated demand) **Economic Behavior**

Demand for Space Cooling Service [GJ-output/m²]

$$Q_{C,t} = k_C \cdot \left(CDD_t \cdot ShellEff \cdot SurfaceRatio_t + \lambda_C InternalGain_t\right) \cdot \left[1 - \exp\left(-\frac{\ln 2}{\alpha_C} \cdot \left(\frac{Y_t}{P_{C,t}}\right)\right)\right]$$

Space Heating Requirement (satiated demand) **Economic Behavior**

Demand for Other Services (water heating & cooking, lighting, other appliances):

$$Q_t = k_i \cdot \left[1 - \exp\left(-\frac{\ln 2}{\alpha_i} \cdot \left(\frac{Y_t}{P_t}\right)\right)\right]$$

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End Use Technologies

Service	Technology	Fuel
Space Cooling		
	Air conditioner	Electric
	Air cooler	Electric
Space Heating		
	Room heater	Electric
	Building heater	Electric
Cooking and Water Heating		
	Gas cooker	Liquefied Petroleum Gas
	Gas cooker	Natural Gas
	Electric cooker	Electric
	Coal cooker	Coal
	Biomass cooker	Commercial biomass
	Traditional biomass cooker	Traditional biomass
	Kerosene stove	Kerosene
Lighting		
	Incandescent bulbs	Electric
	Fluorescent bulbs	Electric
	Solid state lighting	Electric
	Oil Lamp	Kerosene
Appliances	Generic appliance technology	Electric

Share of end use technologies in electricity

Energy Service	Technology	Ownership rate in 1000 households		Yearly usage (days/year)	Daily usage (hours/day)	Average wattage (watts)	Average no. of units		Share of various energy services in household electricity	
		Rural	Urban				Rural	Urban	ShRural	ShUrban
Cooling	AC	2	31	120	9	1950	1	1	1.2%	5.9%
	Cooler	29	182	120	13	185	1	1.5	3.2%	7.1%
Appliances	Fan	384	818	300	7	60	2	3	37.1%	27.9%
	TV	256	661	365	4	140	1	1	20.1%	12.2%
	Fridge	44	319	365	7	220	1	1	9.5%	16.2%
	Wash Mach	1	5	120	1.5	500	1	1	0.03%	0.04%
Lighting	Bulb/CFL/Tubelight	549	923							
	Incand	384	646	365	4	100	1.5	3	24.2%	25.6%
	Flurescent	165	277	365	4	40	1.5	3	4.2%	4.4%
Heating	Space Heating App	5	22	75	4	900	1	1	0.6%	0.7%
						Total Electricity Consumption (MWHr)			**262**	**1106**

How to Model Traditional Biomass?

- In 2005, traditional biomass (TB) accounted for 73% of energy used by rural households in India
- Traditional biomass use in rural areas is assumed to be gradually phased out (No market price but potentially huge non-market price).
- *Full cost of TB-delivered energy service*

  = capital cost of TB-using equipment + time cost of collecting TB

The Long-Term Evolution of India's Building Energy Use

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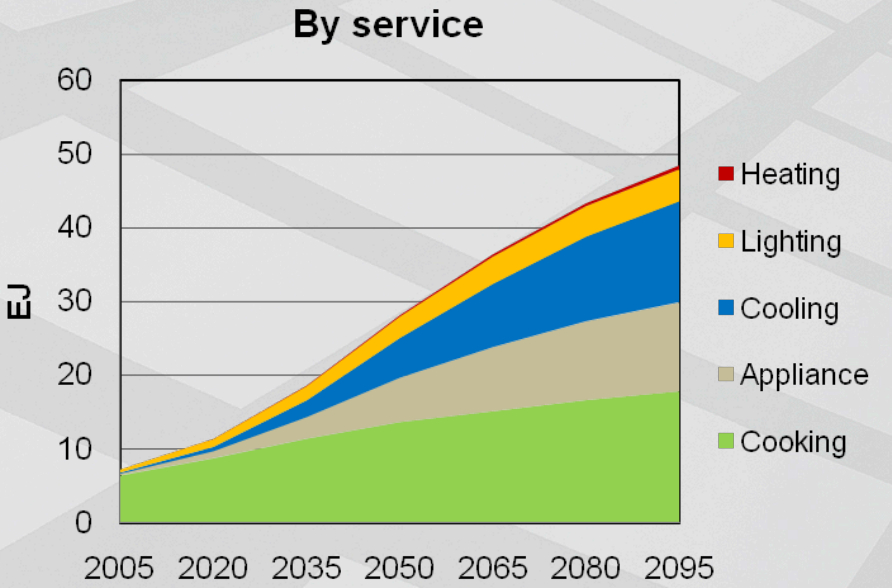
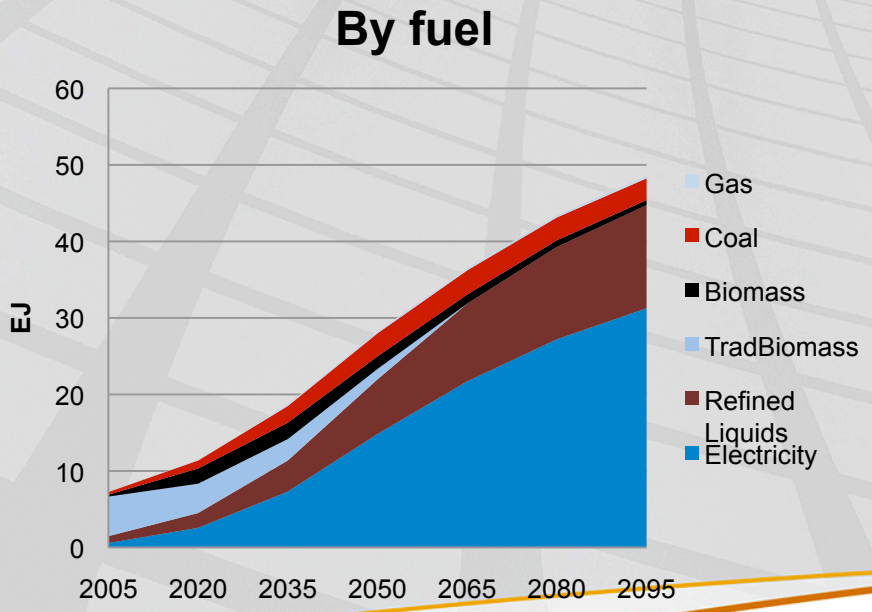
Final energy consumption by Indian buildings

- Very fast electrification:
  rapid expansion of cooling, appliances, and lighting
- Non-electricity energy (LPG and coal) used mainly for cooking





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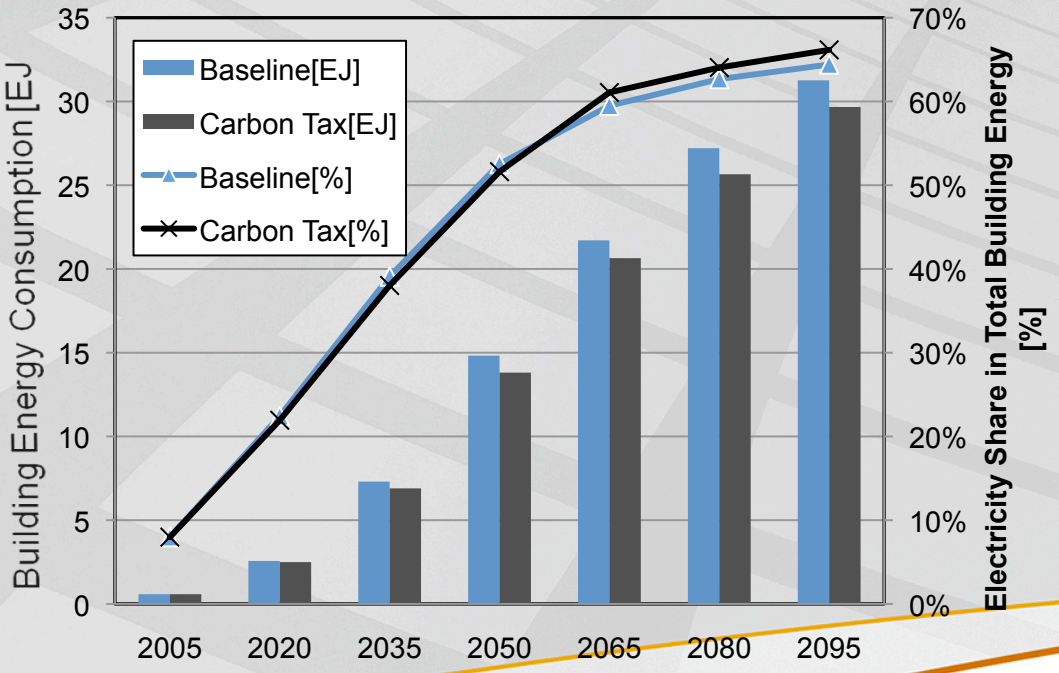
Electrification in Indian Buildings

- Similar to China buildings, the majority of electrification in India occurs simply because of the income-driven growth in electricity-using services, such as cooling, appliances, and lighting.
- Price-induced electrification is very small.



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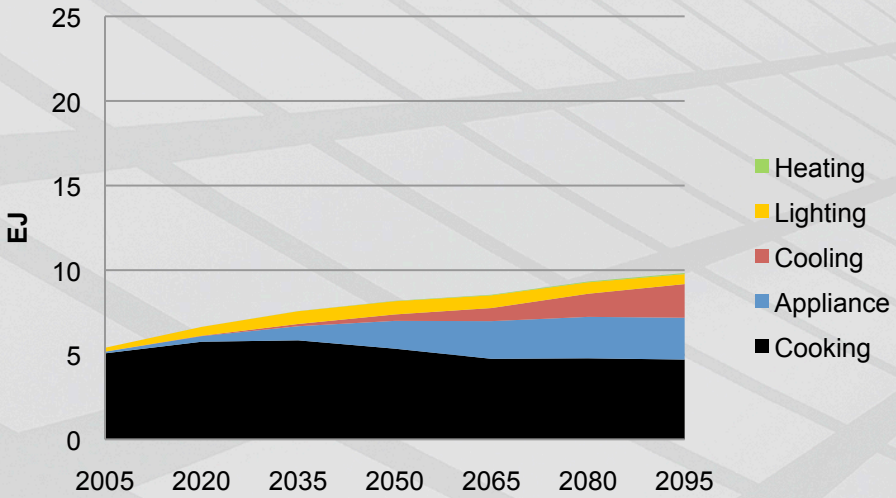
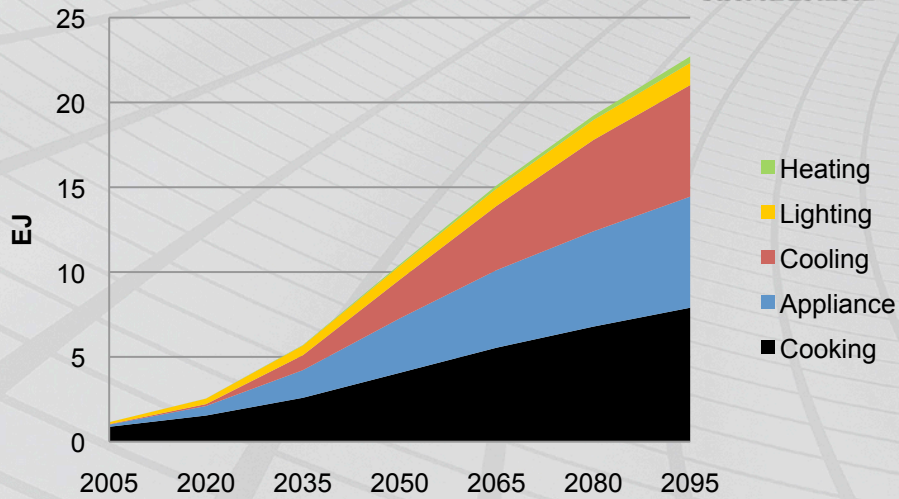
Final energy by service

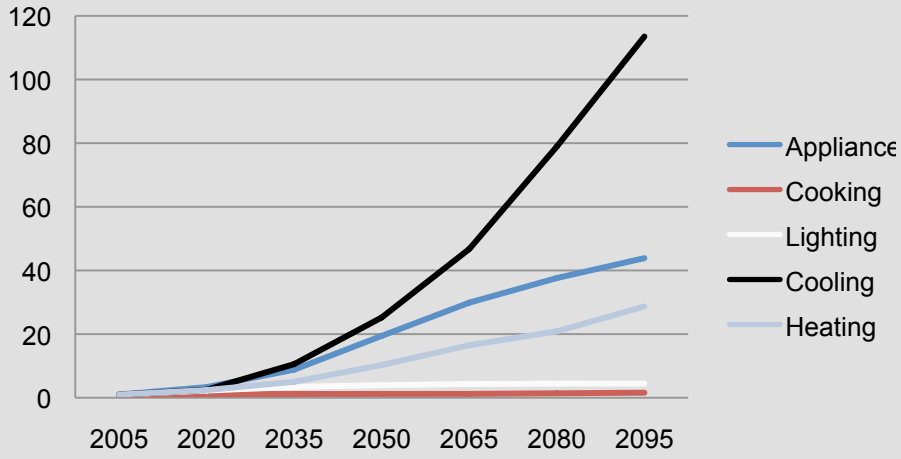
Rural



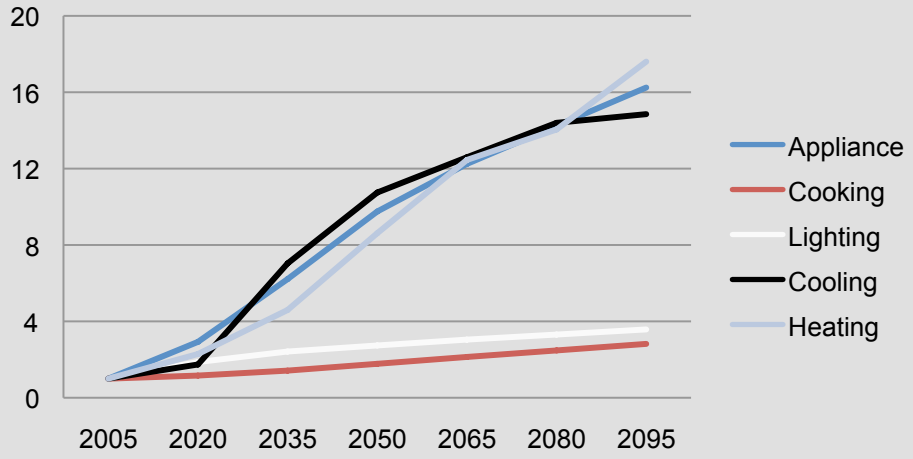
Urban



Index final energy per unit- Rural

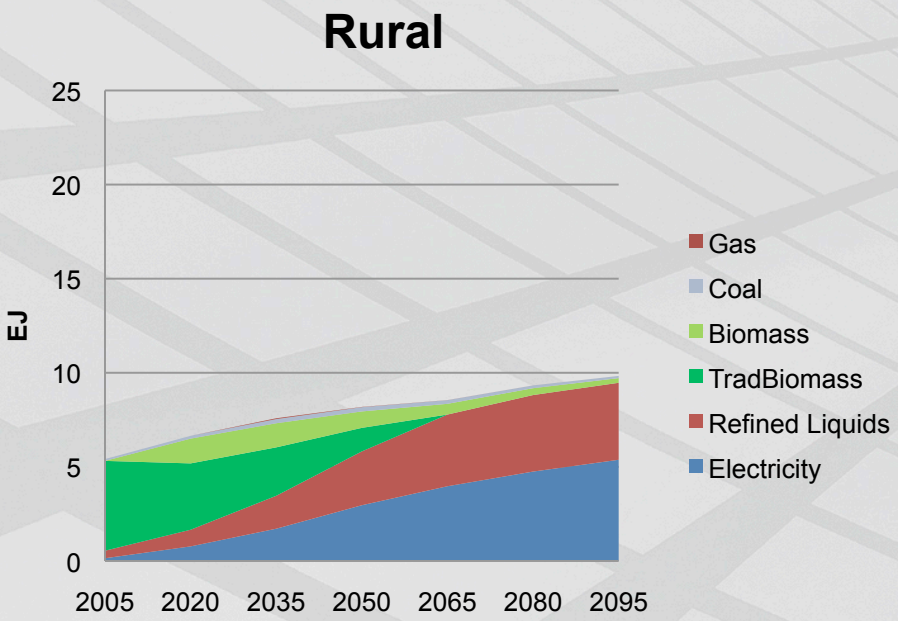


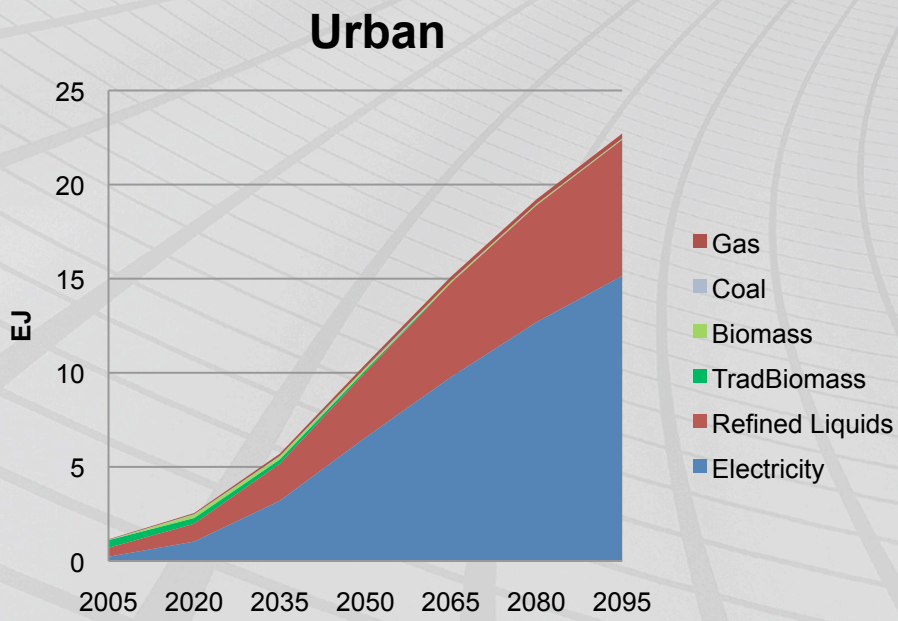
Index final energy per unit- Urban

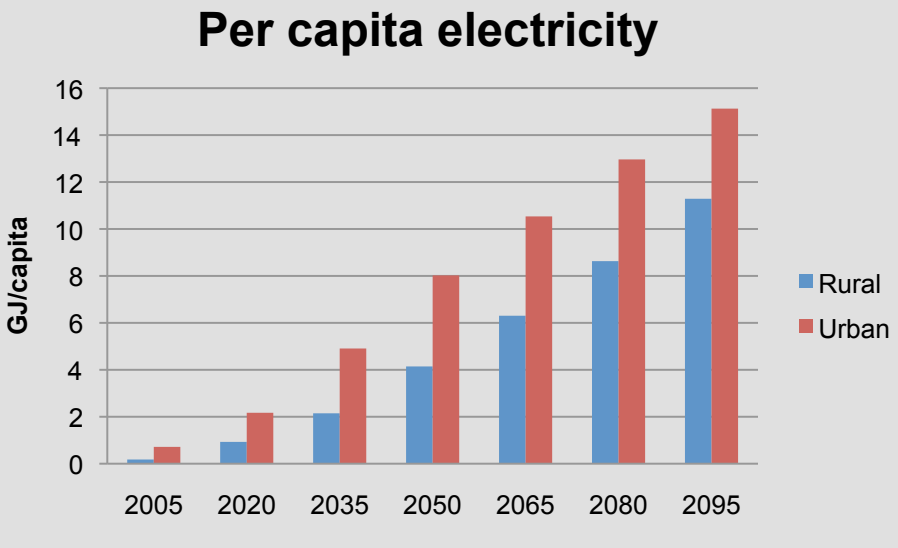


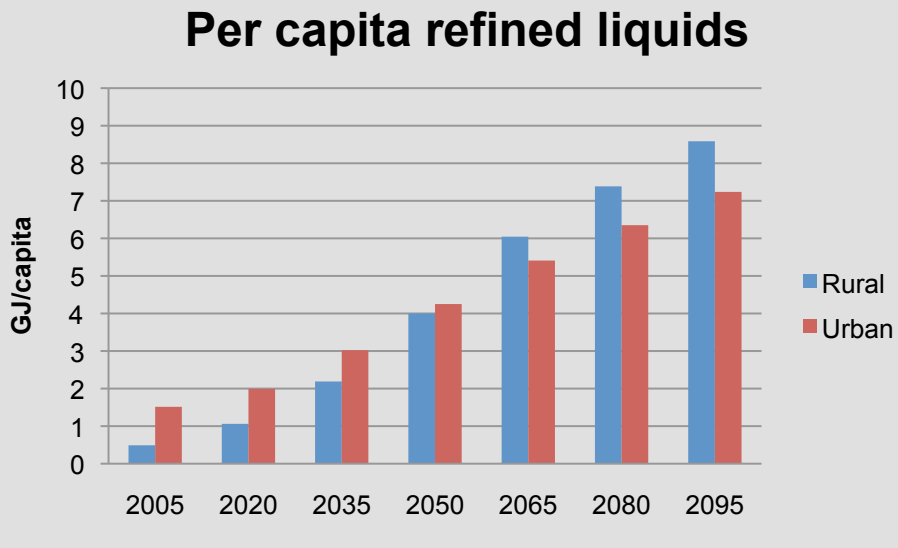
Note: For cooling and heating, service is per unit sq mt and for all other services it is per capita

Final energy by fuel

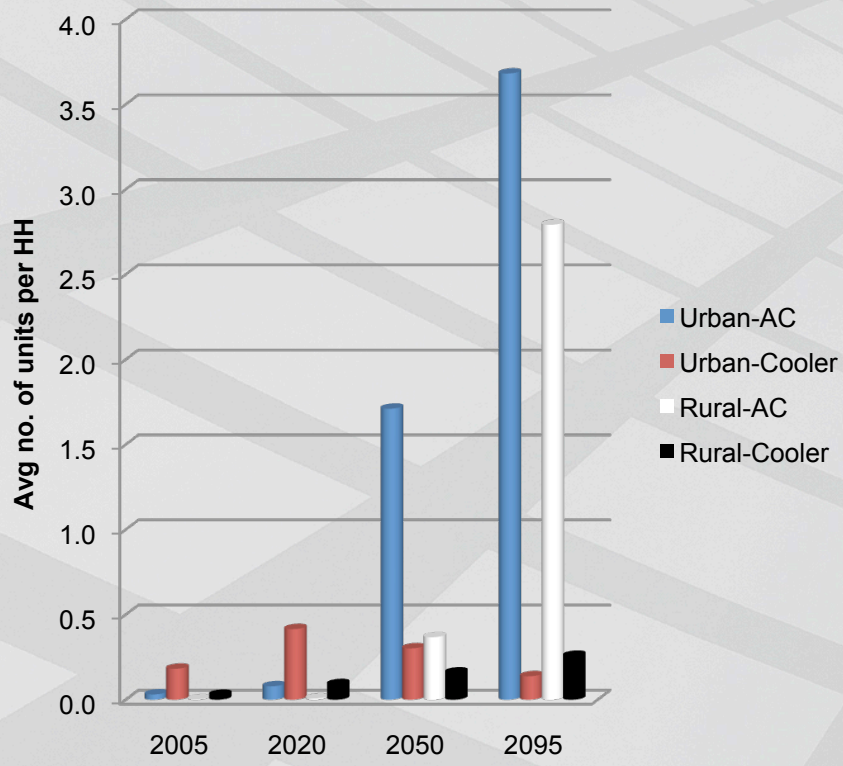








Ownership of heating and cooling technologies

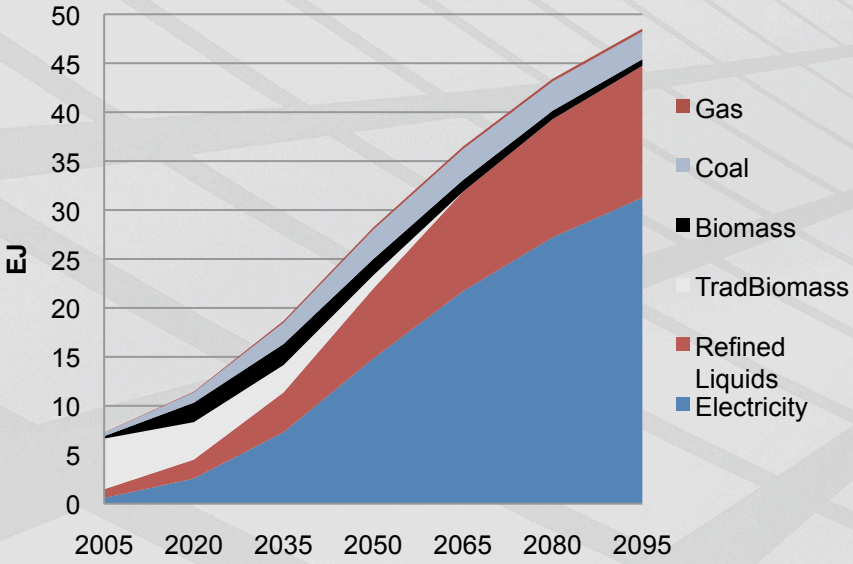


High increase in the penetration of cooling technologies in both rural and urban areas

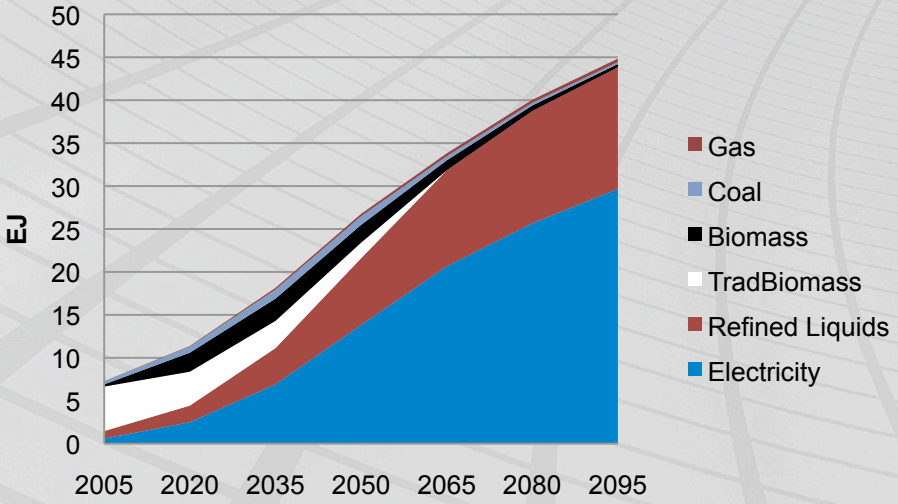
AC demand increases highly in urban areas after 2020 and rural areas after 2050

Impact of Climate Policy

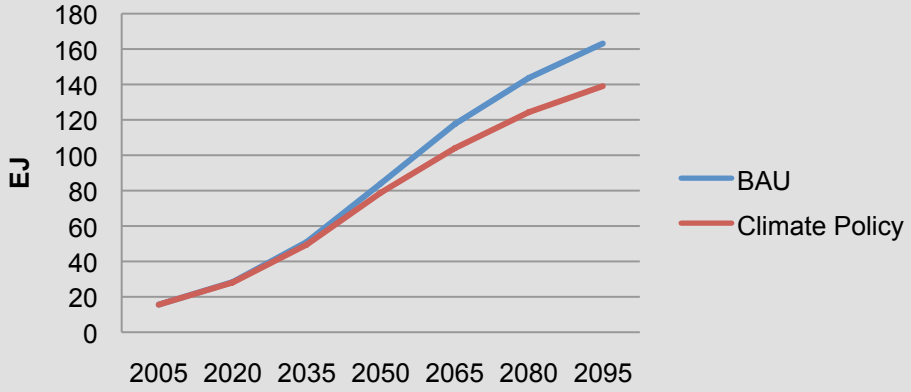
Final energy buildings- BAU



Final energy buildings- Climate Policy



Aggregate final energy for India- BAU



Climate policy aims at 550 ppmv CO_2 concentration in 2095

Total final energy for India decreases by 15% in 2095, Almost 8% decrease in final energy in building sector under a climate policy

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THANK YOU!