Coping with Residential Electricity Demand in India's Future – How Much Can Efficiency Achieve?

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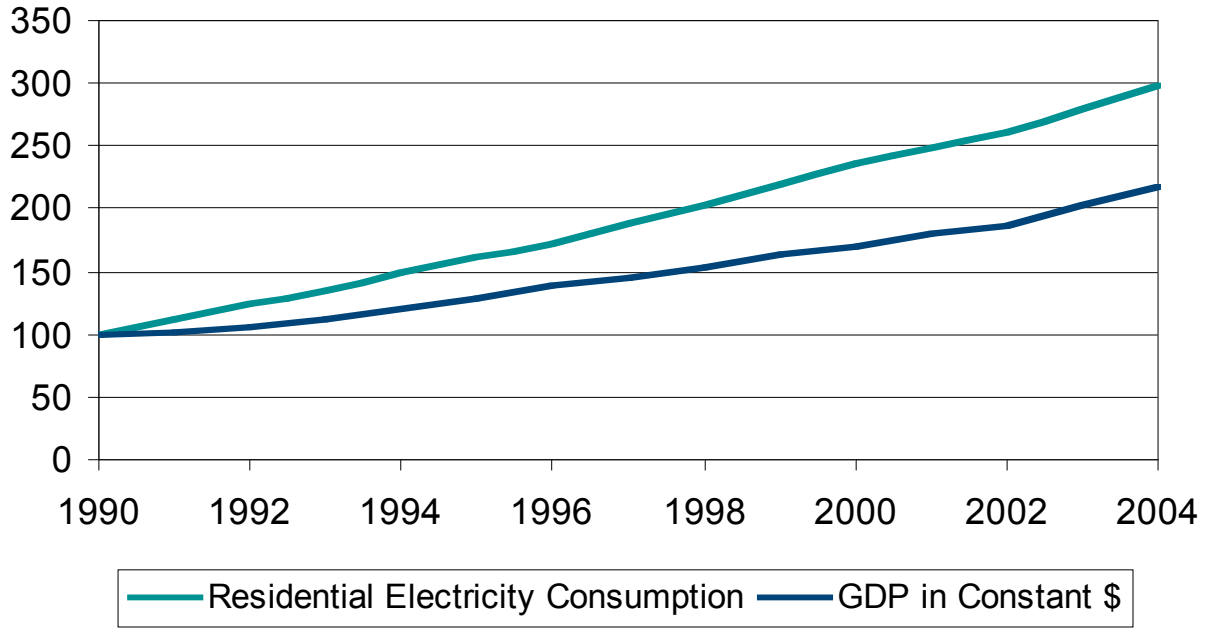
India Residential Electricity Consumption



- Electricity consumption x3 between 1990-2004
- Grows faster than GDP (8% growth for electricity demand vs 6% growth for GDP)
- What will electricity demand be like in 5, 10, 20 years?
- What can energy efficiency policy achieve?

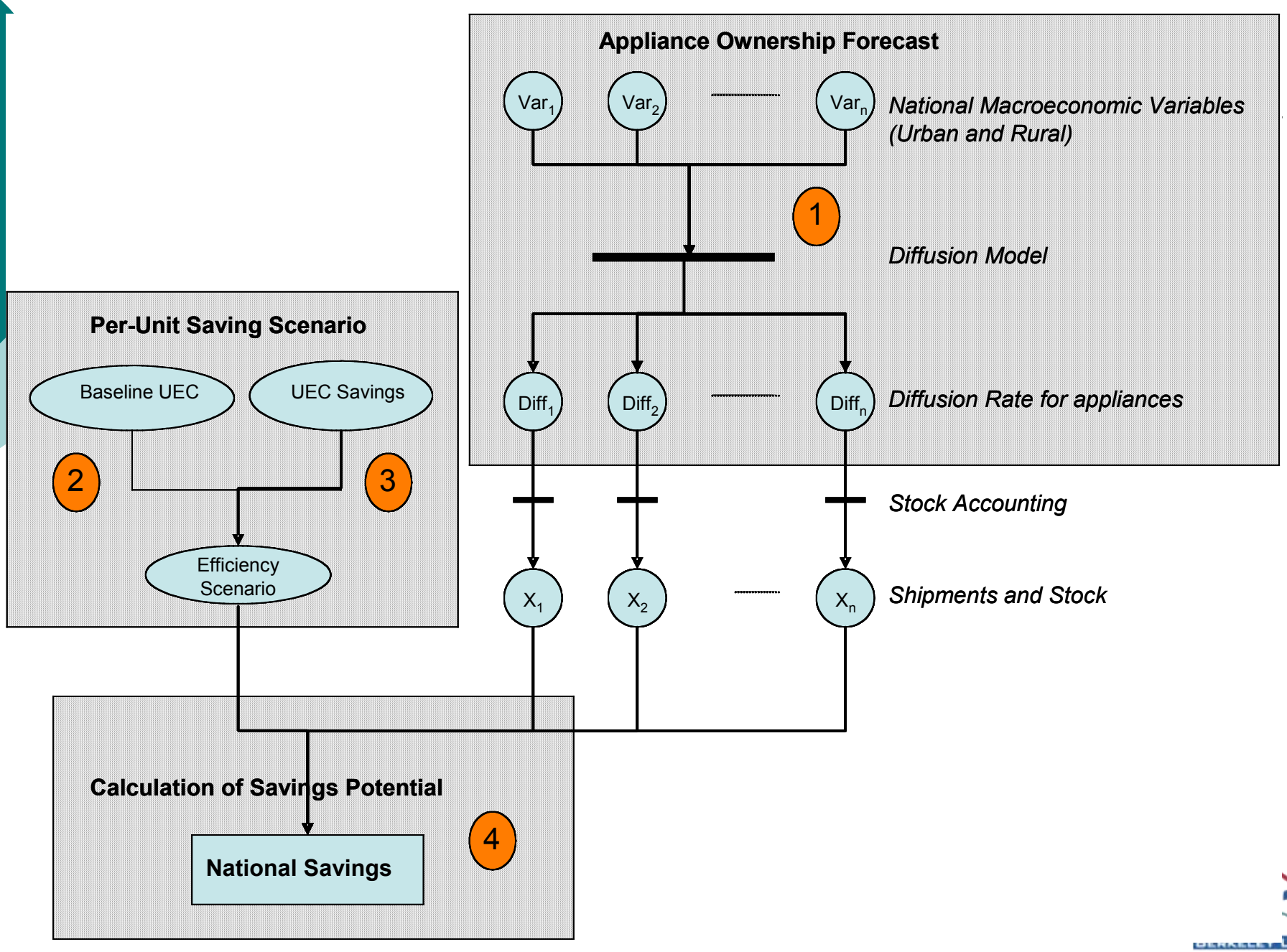
Background

Part of **Global Energy Demand Collaborative** – LBNL initiative towards a *enduse level* forecast of energy related emissions from *all* sectors in *all* regions.

- Modular Analysis Framework allows for focused analysis, such as
  - Country/Sector Studies (**Letschert 2007**)
  - Enduse Studies (McNeil 2007, McNeil 2006)

- Detailed (Enduse and Region) Efficiency Scenarios

Bottom-Up Energy Analysis System (BUENAS)



1 Residential End Uses

- Cover all residential electricity end uses (in different levels of detail)
- Model Rural and Urban Diffusion separately
- Lighting – According to electrification. Number of lamps modeled by income (household expenditure)
- Appliance Ownership: TV, Fans, Refrigerator, AC, Washing Machine and Electric Water Heaters (Geysers).
  - Diffusion (I) = Electrification (I) x Diffusion$_E$ (I)

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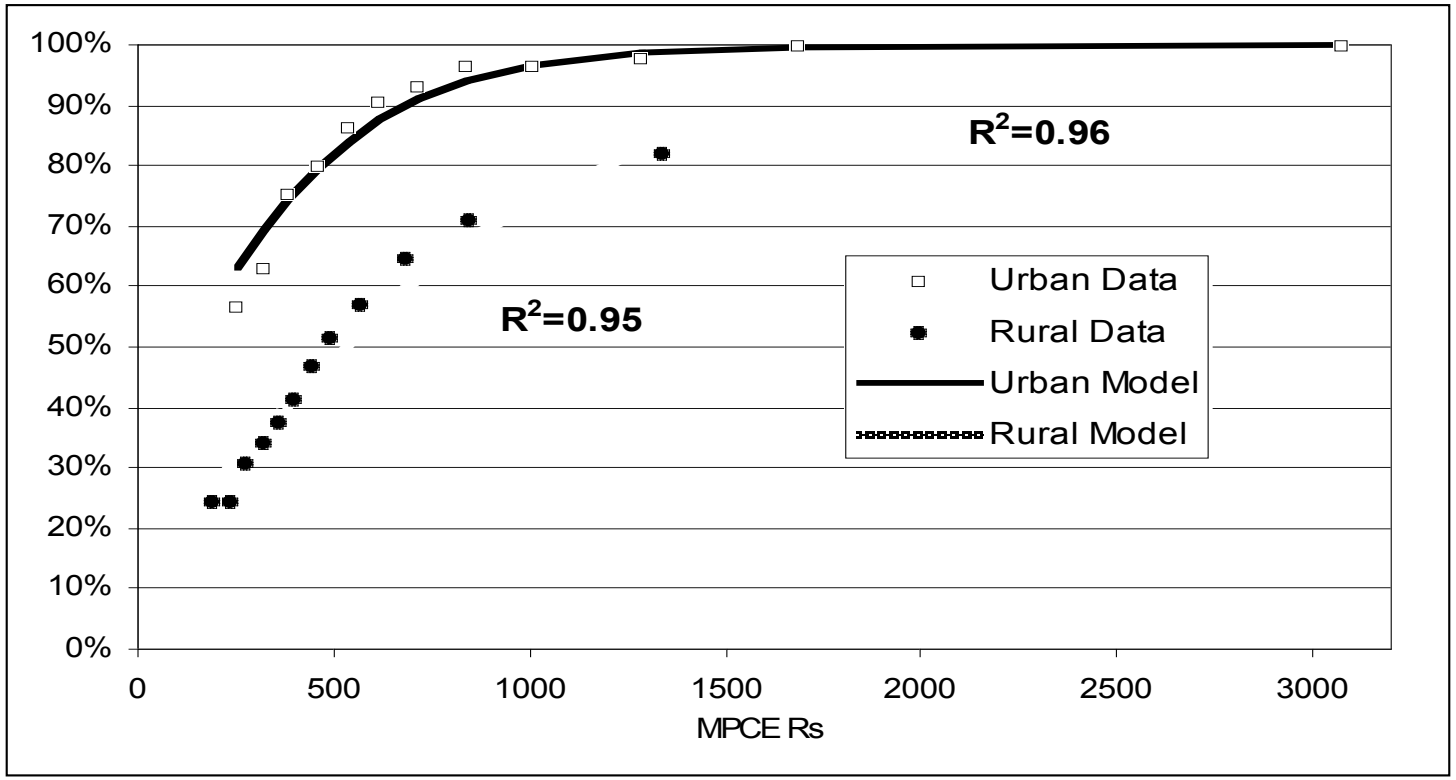
Electrification Model

- Follows S-shaped curve with rapid uptake (Gompertz)

$$\text{Elec} = \exp(\gamma \times (\exp(\beta \times Inc)))$$



Monthly Per Capita Expenditure MPCE is Proxy for Income
Data from National Sample Survey Organization 1999/2000

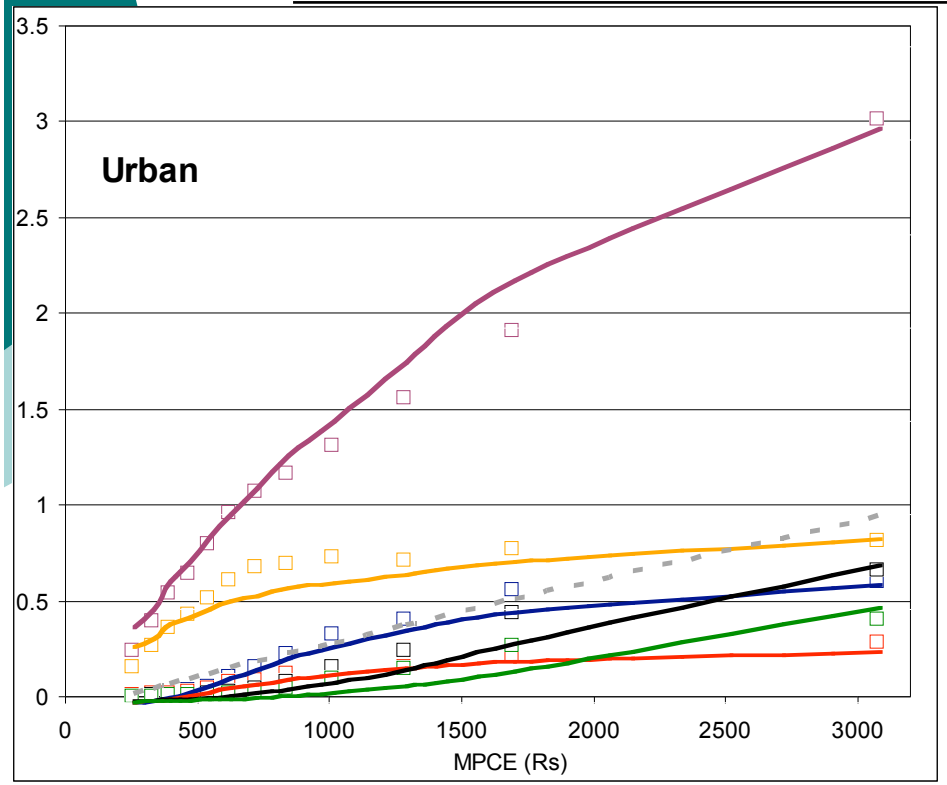
12 Modeling Lighting Consumption

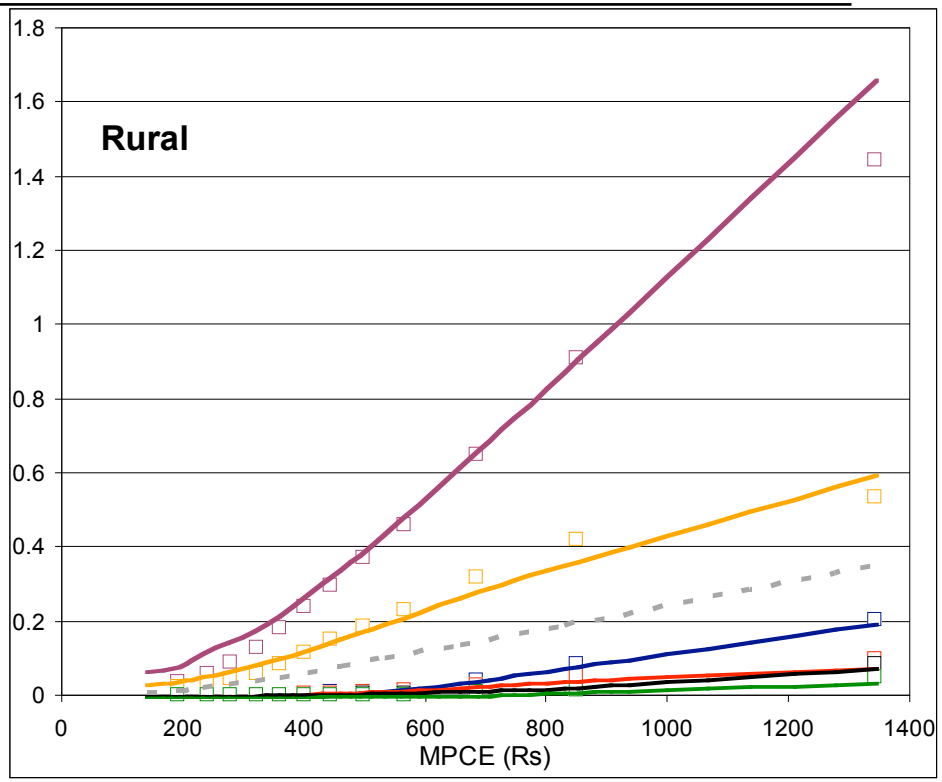
- Electric Lighting Saturation = Electrification Rate
- Lighting Consumption Determined by
  - Breakdown between Incandescent and Fluorescent
  - Number of Bulbs per household as a function of Income
- Consumption Given by
  - Number of Bulbs/Household x Power x Hours of Operation

Source: A.Kulkarni, G.Sant, *Urbanization in search of energy in three Indian Cities**, Energy Vol. 19, No. 5, pp.549-560, 1994

*Pune, Ahmednagar and Talegaon

Modeling Appliance Ownership





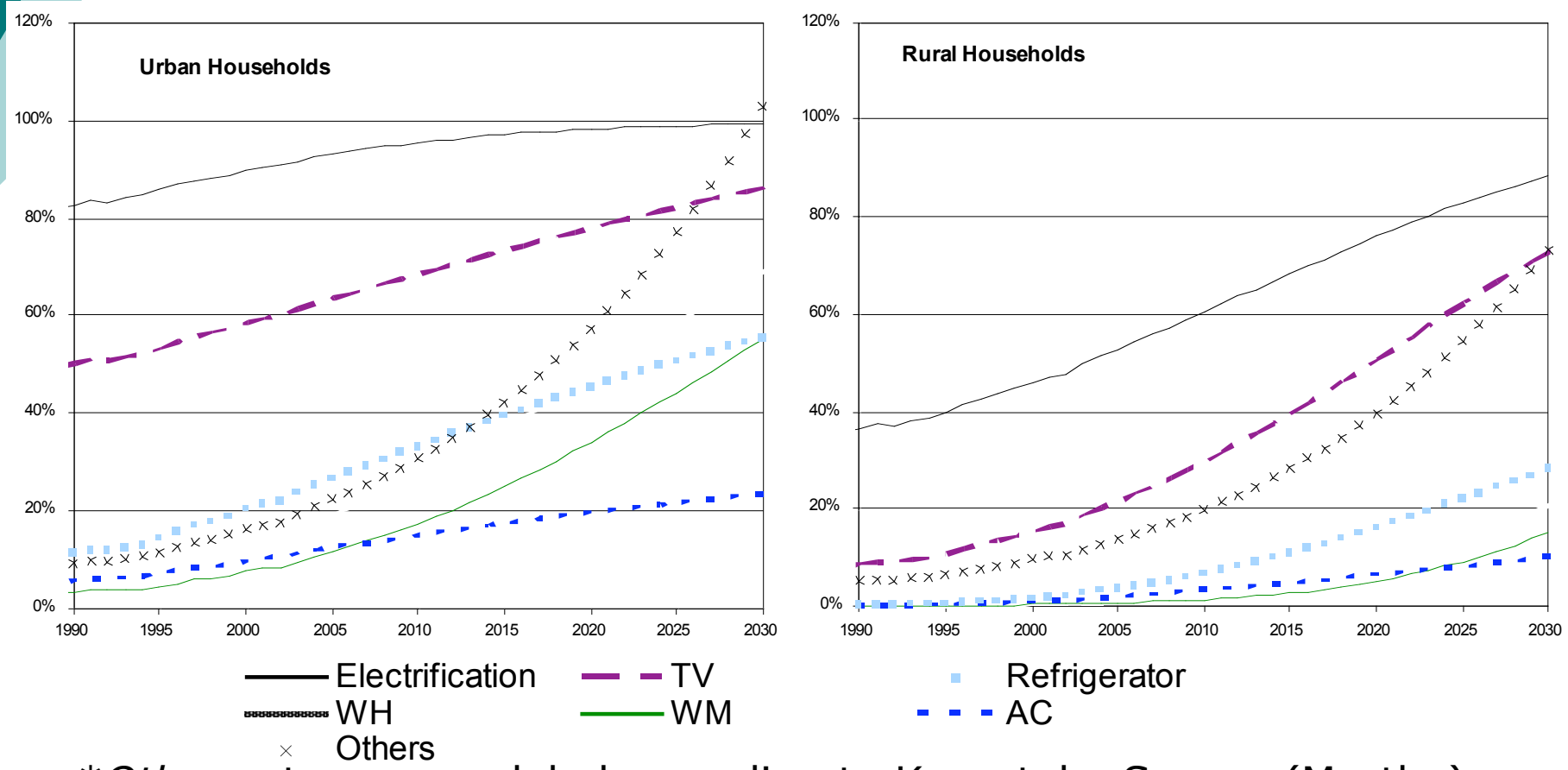
Fan Data TV Data Ref Data AC Data WH Data WM Data

Fan Model TV Model Ref Model AC Model

WH Model WM Model Others

Projecting Appliance Ownership

- 1990-2004: Historical Per Capita Growth Rate (3.7% on average)
- 2004-2030: SRES B2 4.7% per year
- all income categories scale with growth rate



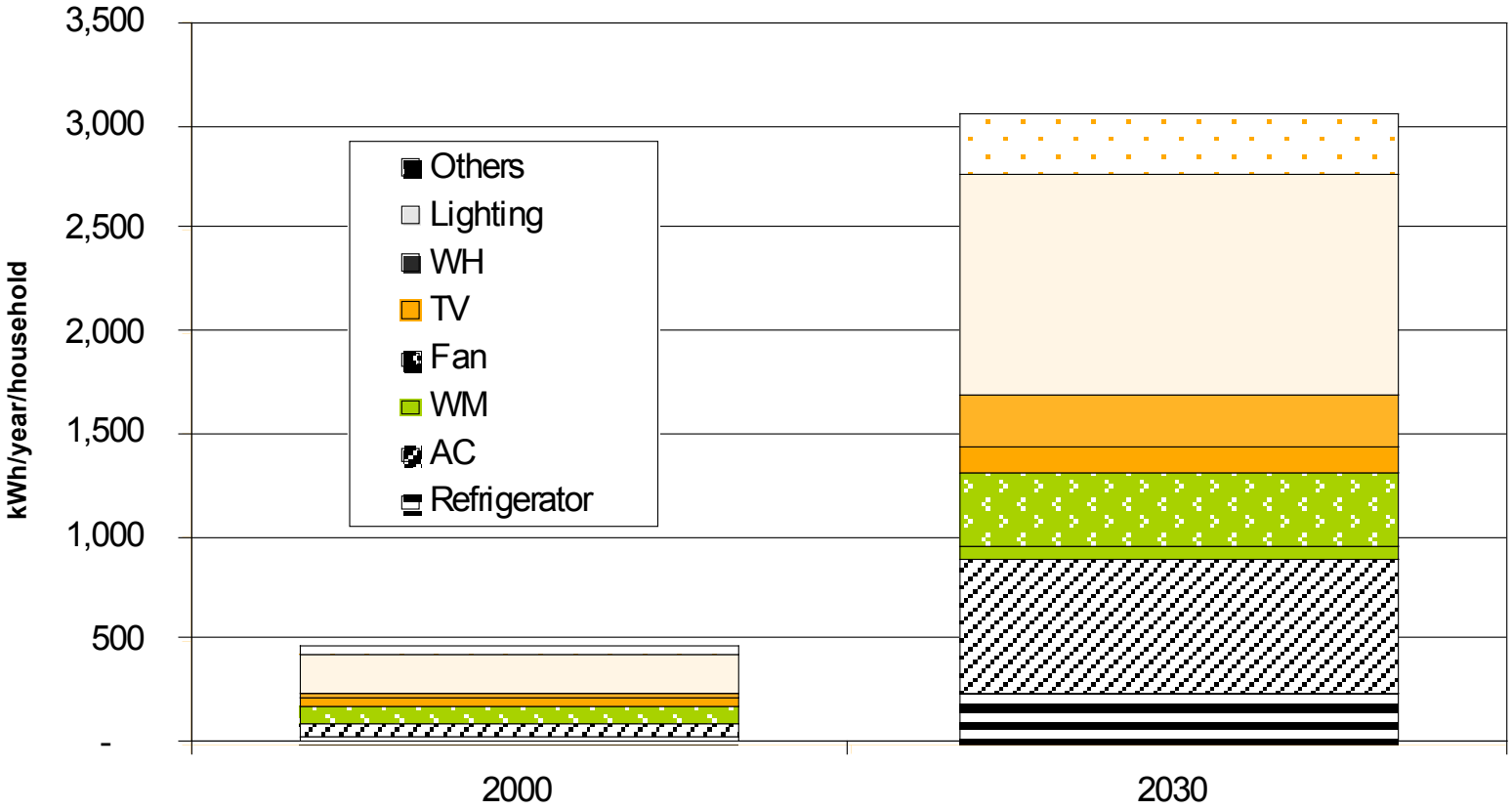
*Other category modeled according to Karnataka Survey (Murthy)

2 Baseline UECs

- Constant except:
  - Refrigerators *(Share of frost-free, 2 door-fridge increases vs Single door)*
  - Air Conditioners *(Function of income)*
  - Water Heaters *(Household Size decreasing)*

	UEC (kWh)		Reference/Assumption	
	2000	2030	2000	2030
Refrigerators	494	657	LBNL Estimates	LBNL Estimates
Air Conditioners	2,160	4,620	LBNL, based on RAMA estimates	Hong Kong in 1996 (Lam,2000)
Washing Machines	190	190	Euromonitor, 2003 and Sanchez, 2006	Euromonitor, 2003 and Sanchez, 2006
Fans	145	145	Karnataka Survey	Karnataka Survey
TV	150	150	Karnataka Survey	Karnataka Survey
Water Heaters	617	591	Reddy, 1995	Reddy, 1995
Fluorescent Tube 40W	58	58	4 hrs a day	4 hrs a day
Incandescent Lamp 60W	88	88	4 hrs a day	4 hrs a day
Others	298	298	Karnataka Survey	Karnataka Survey

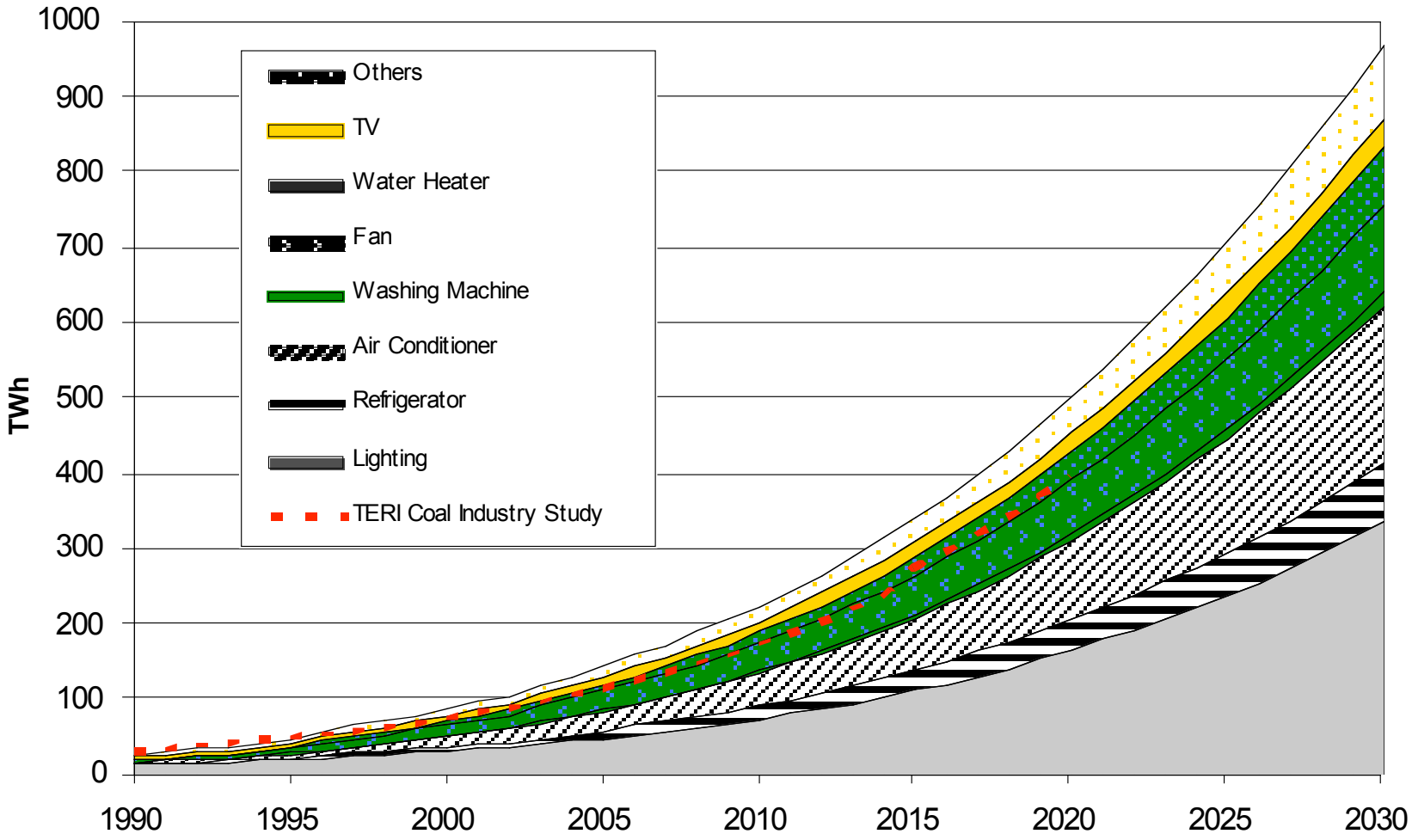
Household Consumption 2000-2030



Urban: 2000 kWh ➔ 4000 kWh

Rural: 250 kWh ➔ 2500 kWh

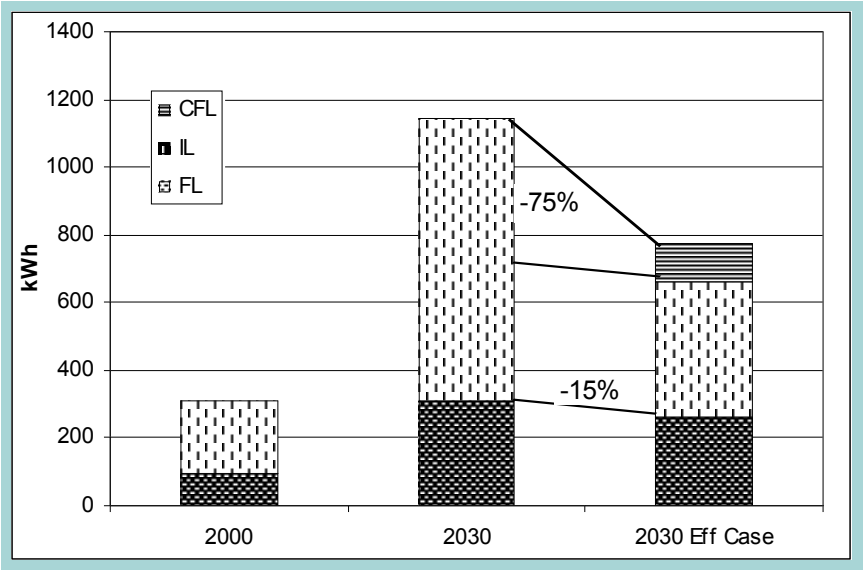
Modeled India Residential Electricity Consumption



3 Efficiency Scenarios

Product	Base case UEC 2010	High Efficiency Case UEC 2010	Efficiency Improvement	Reference
Refrigerators	528	237	55%	TERI
Air Conditioners	2980	2473	17%	RAMA
Ballasts	10 W per fixture	4 W per fixture	6 W	Voice
CFLs	40W	15W	75% per replacement	
Water Heaters	607	455	25%	Voice
Fans	145	100	30%	USDOE
Washing Machines				
Semi-Automatic	125	46	63%	Mexico Data
Automatic	452	325	28%	EU

Example: Lighting UEC with introduction of 1 CFL per Household every 5 years and efficient ballasts



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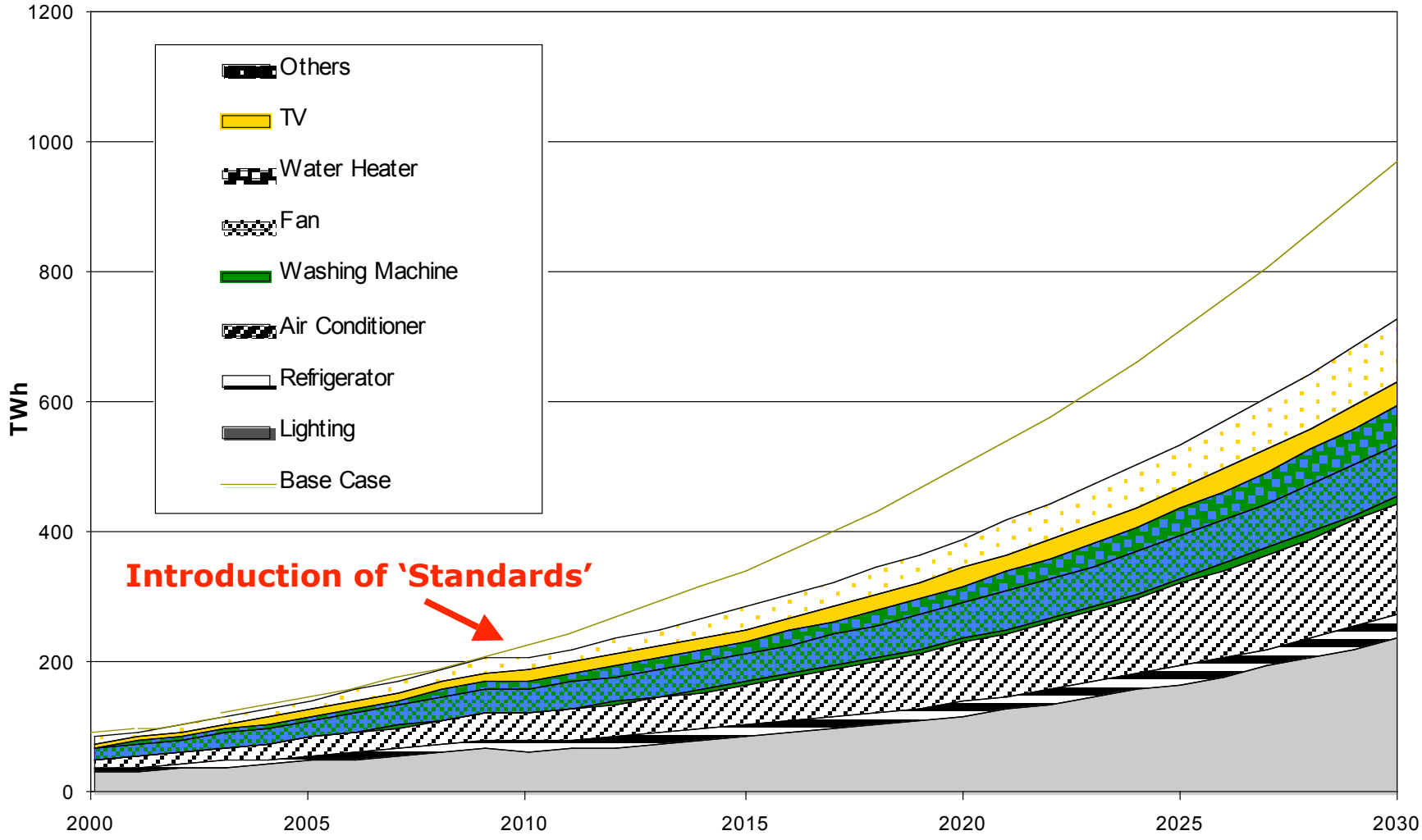
4 Total Electricity Consumption, Base Case and High Efficiency Case



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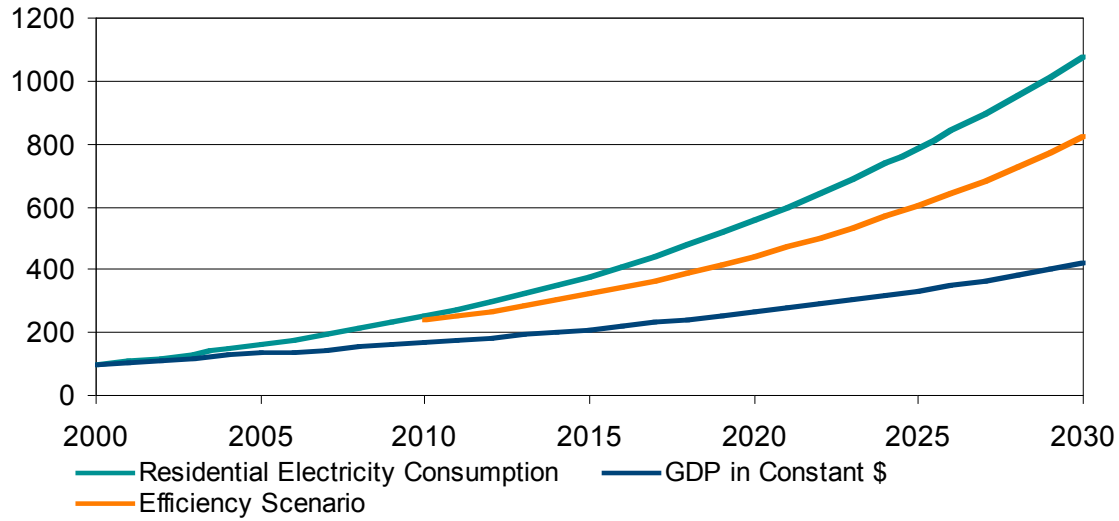
Base Case Consumption, Efficiency Case Consumption, Savings

Year 2030	Base Case Consumption TWh	High Efficiency Case Consumption TWh	Savings TWh	Savings %
Lighting	338	241	97	41%
Refrigerator	77	35	42	18%
Air Conditioner	208	173	35	15%
Fan	116	81	35	15%
Water Heater	78	58	19	8%
Washing Machine	19	10	9	4%
TV	37	37	0	0%
Others	97	97	0	0%
Total	970	733	237	1

Year	Base Case Consumption TWh	High Efficiency Case Consumption TWh	Savings TWh	Savings %	Cumulative Primary Energy Savings Mtoe	Cumulative CO2 Mitigation Mt (CO2)
2005	146	146	0	0%	0	0
2010	226	212	15	6%	14	54
2015	342	287	54	16%	78	298
2020	503	395	108	21%	224	853
2025	710	539	171	24%	473	1,802
2030	970	733	237	24%	834	3,176

Conclusion

- Electricity consumption x10 between 2000 and 2030



- About 1/3 of savings from Lighting – ½ from REF+AC+FAN
- 25% of Electricity Saved in 2030 – about 5 years of growth
- Further reductions require fresh ideas.

Thank you!

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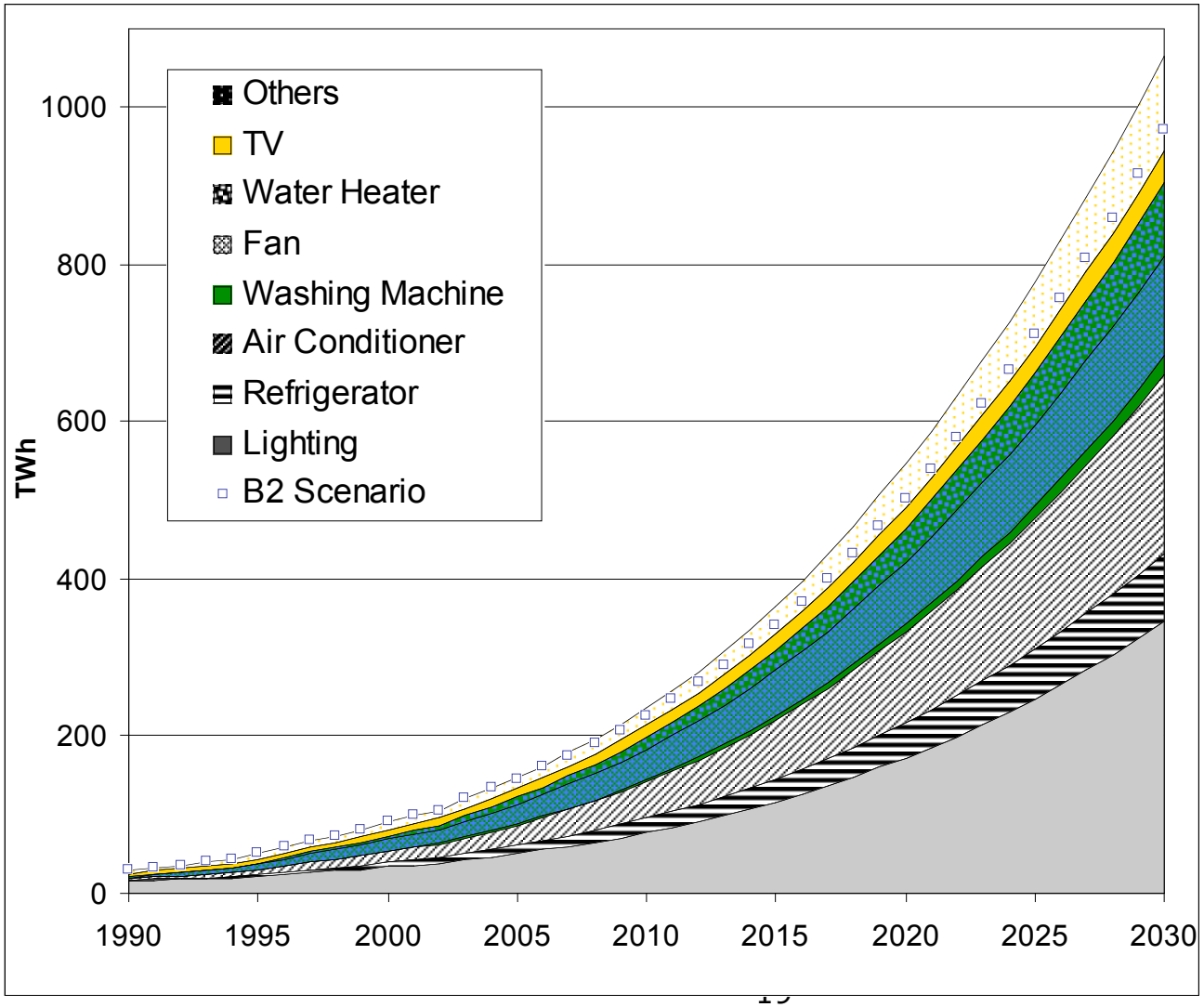
Extra Slides

Residential Consumption in A1 scenario (5.5% per cap)



Equations and Results of the Fits

$$Diff = Elec \times \alpha \times \exp\left(\gamma \times \exp\left(\beta \times Inc\right)\right)$$

Linearization:

$$\ln\left(\ln\left(\frac{\alpha}{Diff} \times Elec\right)\right) = \ln(-\gamma) + \left(\beta \times Inc\right)$$

Urban			Coefficients	Standard Error	P-value	Rural			Coefficients	Standard Error	P-value
Refrigerator		ln γ	3.289	0.124	1.4E-10	**Refrigerator**		ln γ	3.169	0.056	2.0E-09
R Square = 0.96	α=1	β	-3.1E-01	1.9E-02	1.4E-08	R Square = 0.99	α==1	β	-2.7E-01	8.7E-03	7.3E-08
Air Conditioner		ln γ	4.690	0.273	9.3E-09	**Air Conditioner**		ln γ	3.114	0.323	2.2E-06
R Square = 0.97	α=1	β	-7.4E-01	4.1E-02	5.7E-09	R Square = 0.88	α=1	β	-4.6E-01	5.3E-02	5.9E-06
Washing Machine		ln -γ	1.787	0.088	1.8E-09	**Washing Machine**		ln -γ	1.959	0.050	2.9E-12
R Square = 0.90	α=1	β	-7.1E-04	7.3E-05	2.0E-06	R Square = 0.85	α=1	β	-6.4E-04	8.4E-05	1.8E-05
Fan		ln -γ	0.688	0.054	1.7E-07	**Fan**		ln -γ	1.152	0.084	8.7E-08
R Square = 0.98	α=35	β	-8.9E-04	4.5E-05	2.2E-09	R Square = 0.90	α=35	β	-1.3E-03	1.4E-04	2.9E-06
TV		ln -γ	-0.322	0.177	9.9E-02	**TV**		ln -γ	0.940	0.106	4.9E-06
R Square = 0.58	α=1	β	-5.5E-04	1.5E-04	3.9E-03	R Square = 0.89	α=1	β	-1.6E-03	1.8E-04	4.8E-06
Water Heater		ln -γ	1.797	0.088	1.7E-09	**Water Heater**		ln -γ	1.900	0.057	1.4E-11
R Square = 0.95	α=1	β	-9.7E-04	7.3E-05	1.1E-07	R Square = 0.85	α=1	β	-7.2E-04	9.5E-05	1.7E-05

: Follow a modified form of the gompertz function

Shipment and stock turn over

- How fast efficient products enter the stock => determines average efficiency
- Depends on:
  - First purchase (due to population growth and **diffusion growth**)
  - Replacements of old appliances (directly function of lifetime of appliance)

	Shipments in Millions		Growth Rate	Stock in Millions		Growth Rate
	2000	**2030**		**2000**	**2030**	
Refrigerator	1.8	10.8	6.1%	12.9	125.0	7.9%
AC	1.0	4.3	5.1%	7.4	50.9	6.7%
Washing Machine	0.7	10.7	9.6%	4.4	101.0	11.0%
Fan	13.9	66.4	5.3%	122.3	803.3	6.5%
TV	5.3	19.6	4.5%	52.2	249.7	5.4%
Water Heater	1.2	13.0	8.4%	7.8	130.5	9.8%
Fluorescent Tubes	32.5	260.3	7.2%	191.1	1588.4	7.3%
Incandescent Bulb	114.7	1,192.2	8.1%	281.0	2846.6	8.0%

1 Appliance Ownership Forecast- Household Surveys

- Appliance Ownership statistics for different income (expenditure) categories
  - NSSO 1999/2000
- Lighting Model
  - Energy use in three Indian Cities
- Water Heater and "Others" Saturation
  - End Uses of Electricity in Households of Karnataka state

Strategy

1. Forecast Stock (ownership) based on economic growth
2. Estimate Baseline Unit Energy Consumption
3. Estimate cost effective efficiency improvements at the end use level
4. Combine with stock accounting to get consumption scenarios

1

Electrification Model

- Follows a Gompertz equation:

$$\text{Elec} = \exp(\gamma \times (\exp(\beta \times Inc)))$$

- Linearization:

$$\ln(\ln(\frac{1}{\text{Elec}})) = \ln(-\gamma) + \beta \times Inc$$