A Power Sector Analysis for Cuba Using the MARKAL/TIMES Model

International Energy Workshop

Fondazione Giorgio Cini, Venice, Italy

June 19, 2009

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This analysis was conducted by International Resources Group for the U.S. Agency for International Development.

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Outline

- Analysis context and goals
- Scenario “storylines” and sensitivity cases
- Model structure and inputs
- Results and analysis
- Key sensitivities

Analysis Context

- Island nation with an isolated power sector, historically dependent on external support
  - Domestic gas and oil reserves, presently investment constrained
- Power generation relies on
  - Aging heavy fuel oil plants, in poor condition due to burning of heavy, sour domestic crude,
  - Recent addition of natural gas plants financed through international joint venture
  - More than 1 GW in small gensets added to address power crisis
- Large number of uncertainties for the future energy system
  - Rate of economic growth and international fuel prices
  - Rate and nature of market liberalization
  - Openness to and availability of foreign investment
  - Changes in the structure of energy demand

Analysis Goals

- Assess cost effective power sector investment options over the period 2007-2025
- Consider various scenarios of
  - Electricity demand growth
  - Domestic oil, gas, and bagasse production
  - Availability and cost of imported fuels
  - Rate of possible investment in infrastructure
- Report on resulting investment needs, technology choices, costs, and CO_2 emissions.

Scenarios Assessed

- Scenarios were divided into two sets, or “storylines”:
  - Business as usual (BAU), which assumes continued moderate electricity load growth, limited foreign investment in the oil and gas sector, and hence limited production growth
  - Rapid economic growth and high foreign investment (HI), which assumes higher electricity load growth, accelerated foreign investment, rapid increase in domestic fuel production, and transition to market pricing of electricity
- Each scenario set included sensitivities that explore the impacts of:
  - Fuel prices (higher gas, lower oil, lower coal)
  - Restrictions on new power plant and LNG import infrastructure investment
  - High bagasse availability due to a revitalized sugar/ethanol industry

Model Structure and Input Data

- A power and supply sector-only, elastic demand MARKAL model was constructed
- Input data included:
  - Existing power plants, characterized by external assessment, including assumed costs for continued maintenance based on recent major maintenance expenditures
  - Future power plant options, based on international data (AEO2009)
  - Domestic fuel production potential based on USGS assessment and assumed rates of development
  - Fuels priced at AEO2009 international prices
  - Electricity load growth as scenario inputs

Key Scenario Inputs for BAU and HI

Electricity Demand (GWh)	2007	2010	2013	2016	2019	2022	2025	Ann. %
BAU	13,740	14,948	16,262	17,691	19,246	20,937	22,778	2.8%
HI	13,740	15,927	18,462	21,401	24,807	28,756	33,333	5.0%

- BAU demand grows at 1998-2007 average rate
- HI assumes faster economic growth and penetration of intensive end uses, does not include any endogenous demand-reduction effects of a move to market prices (calculated within the model)

Oil and Gas Production	2007	2010	2013	2016	2019	2022	2025
BAU - Oil (bbl/day)	51,733	53,421	55,164	56,964	58,823	60,742	62,724
HI - Oil (bbl/day)	51,733	53,421	103,025	152,628	251,836	251,836	251,836
BAU - Gas (bcf)	43.0	45.6	48.4	51.4	54.5	57.9	61.4
HI - Gas (bcf)	43.0	59.3	93.6	127.9	196.4	196.4	196.4

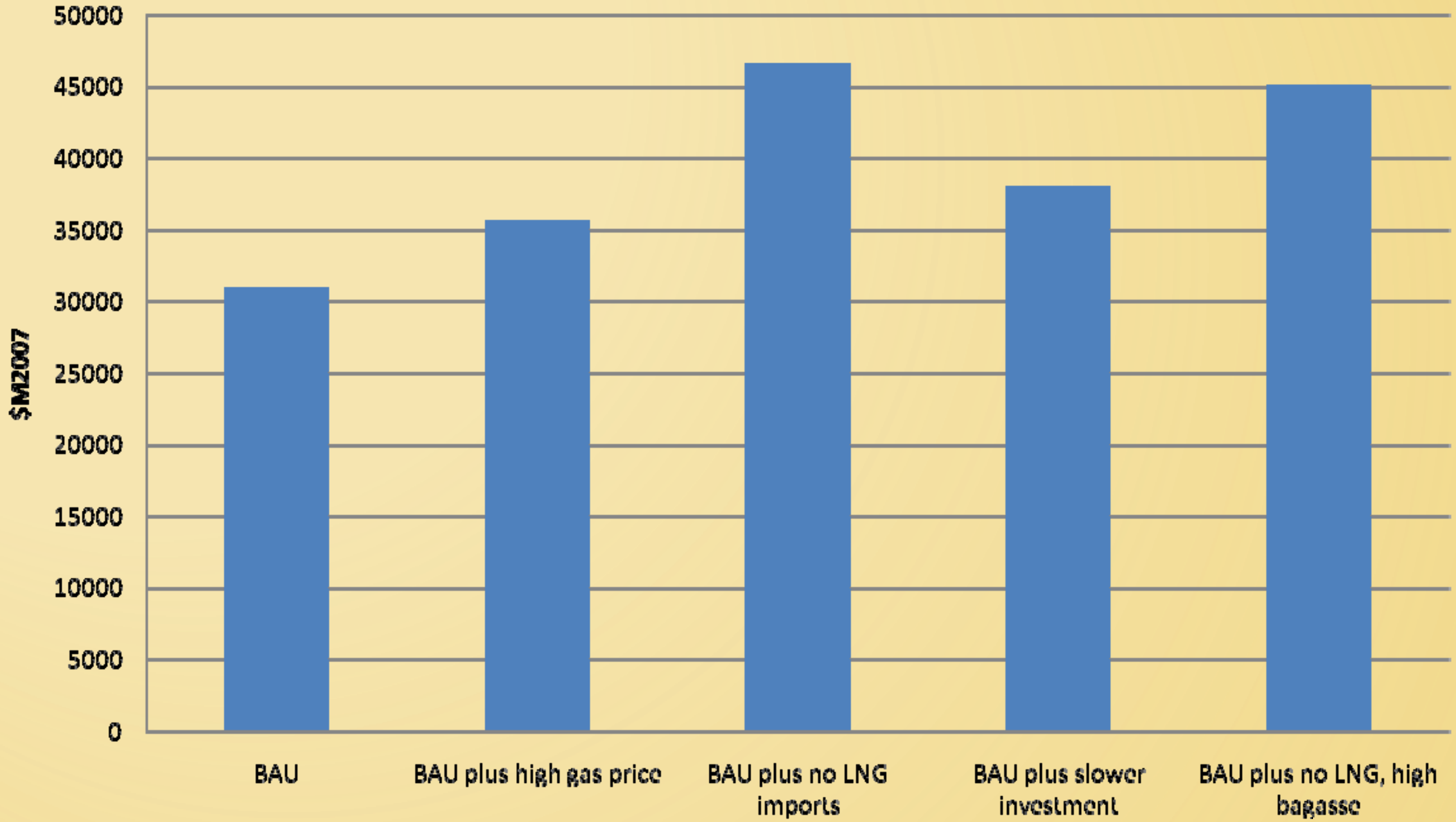
- BAU assumes continued slow growth of oil and gas production
- HI assumes that major investment converts USGS assessment mean resources into available reserves; production ramps up by 2020

Key Findings

- Natural gas is the cost effective fuel, even in cases where natural gas prices are increased 40% above AEO2009 projected levels and oil prices are decreased 40% below AEO2009 levels (but see coal, below)
- Given current assumptions, importing LNG is cost effective in every scenario, suggesting LNG import costs are a key area for further analysis
  - Restricting LNG import substantially increases system costs
- It is cost effective to replace all existing heavy fuel oil (HFO) power plants at once, with new natural gas combined cycle power plants
  - Restrictions on the speed with which this can be done are a primary determinant of system costs and electricity prices
  - Once the system has made these replacements, subsidies are no longer needed to maintain electricity prices at or below current levels
- Wind and sugarcane bagasse resources become valuable when LNG import is restricted
- Importing coal for power production is not cost effective, except in the case of high gas prices and reduced coal prices

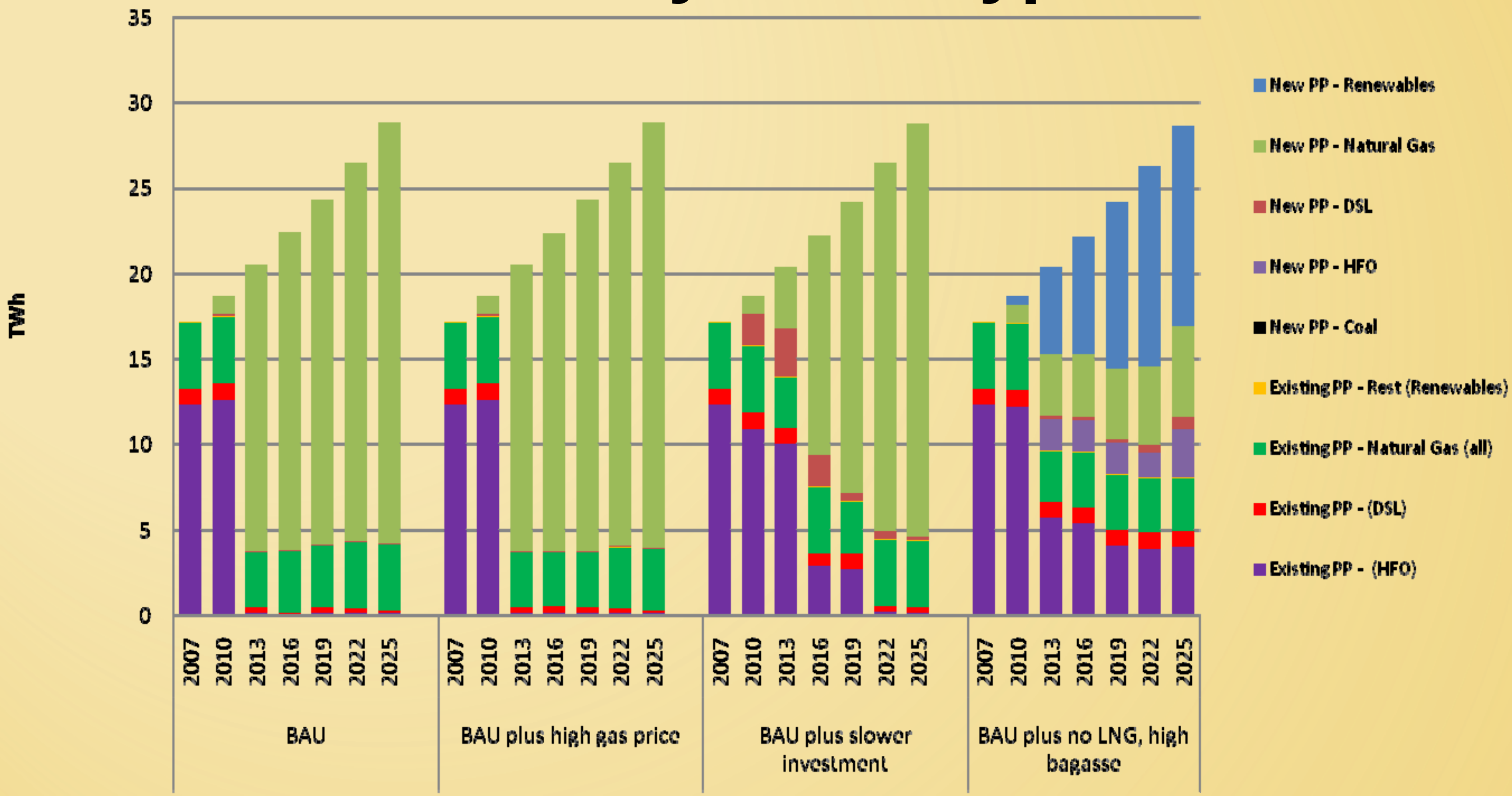
BAU Scenarios

Total System Cost - BAU



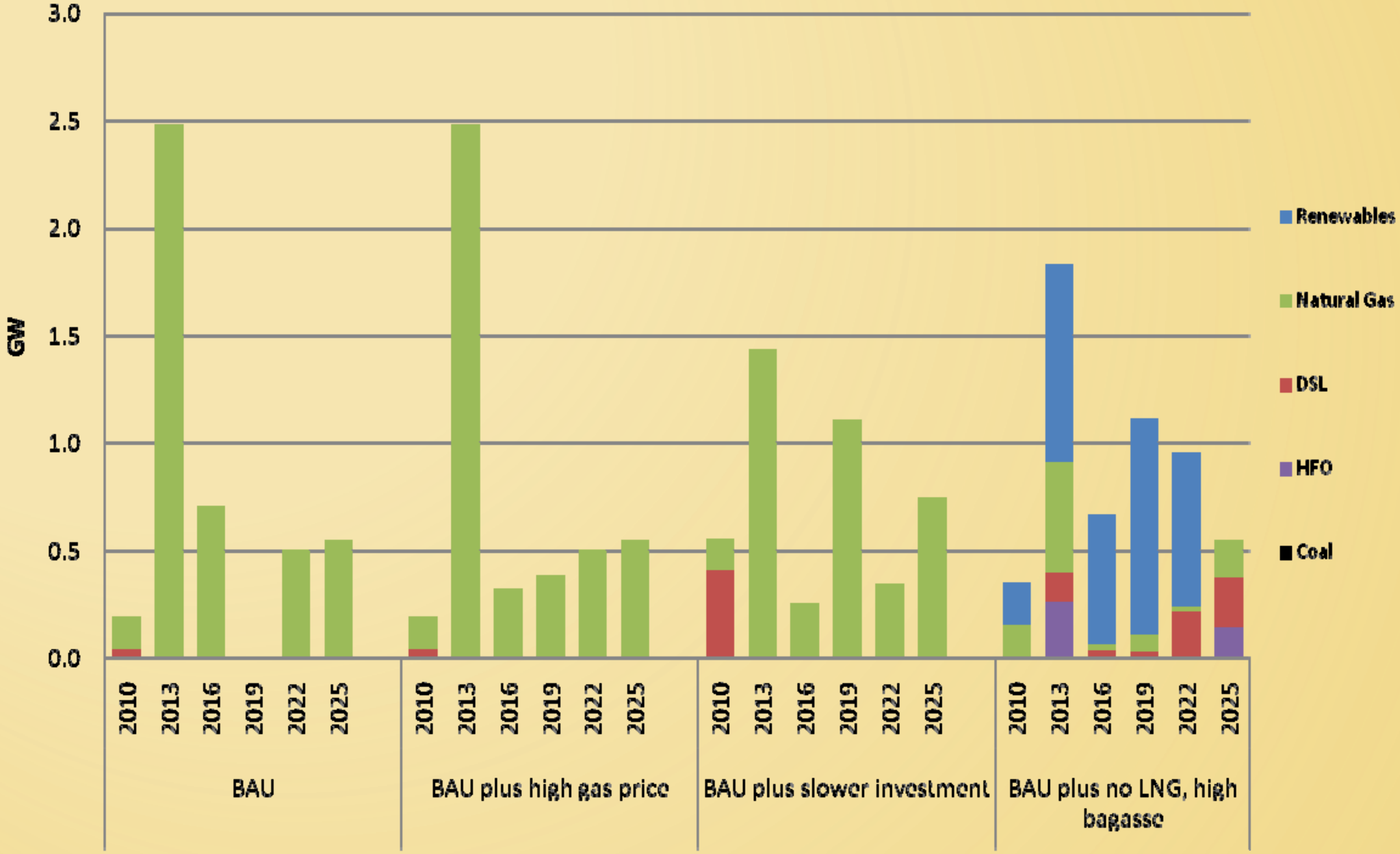
- Because of limited domestic gas production growth, the BAU system is very sensitive to changes in external conditions.
  - A 40% increase in gas prices increases system cost by 15%
  - An inability to import LNG increases system cost by 50%

Generation by Plant Type - BAU



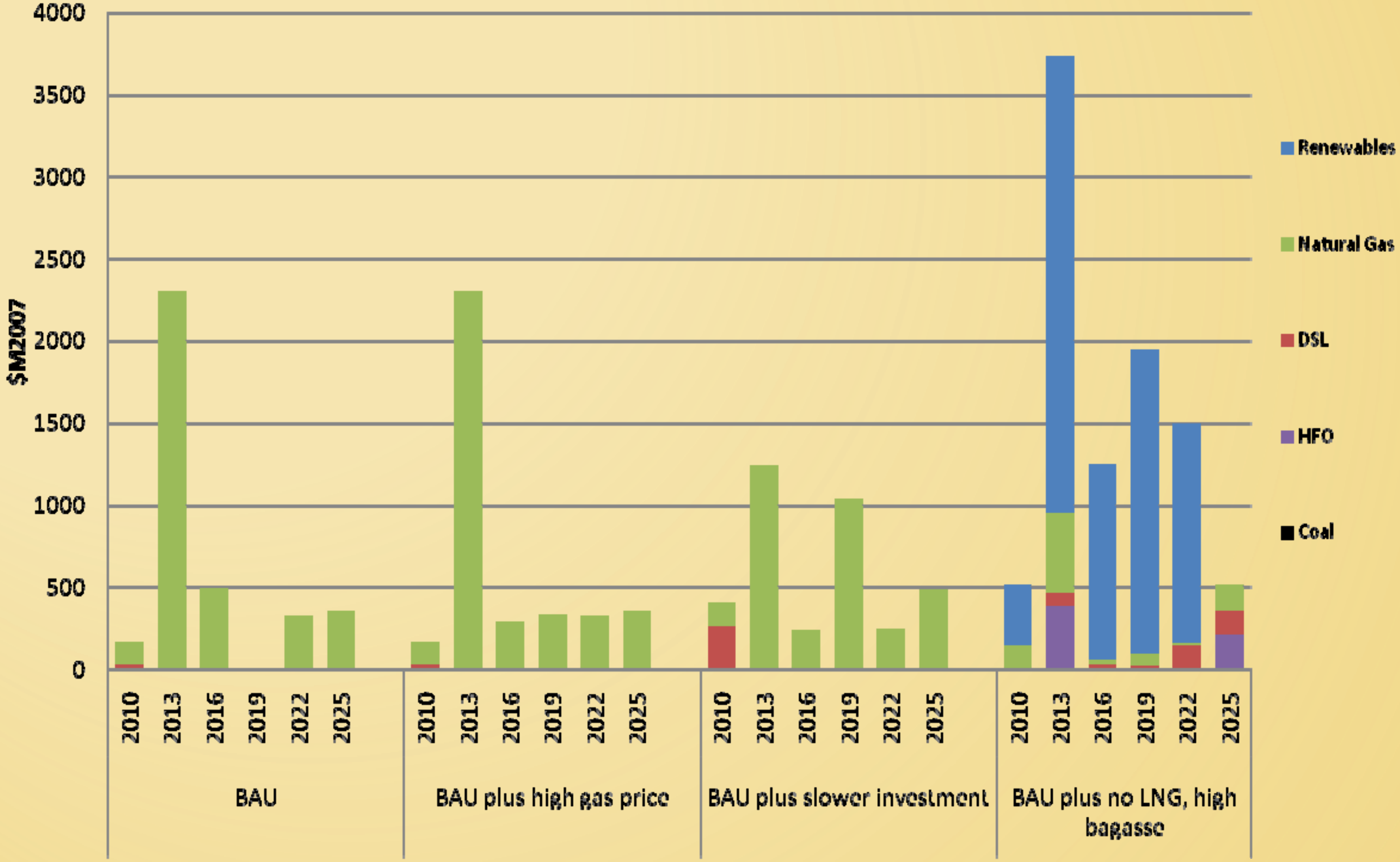
- When unrestricted, new natural gas becomes the dominant plant type
- When the rate of new investment is constrained, existing HFO plants must continue to operate for some time
- When LNG imports are restricted, the system maintains the more efficient existing HFO plants and builds new HFO steam, wind, and bagasse

New Power Plant Capacity - BAU



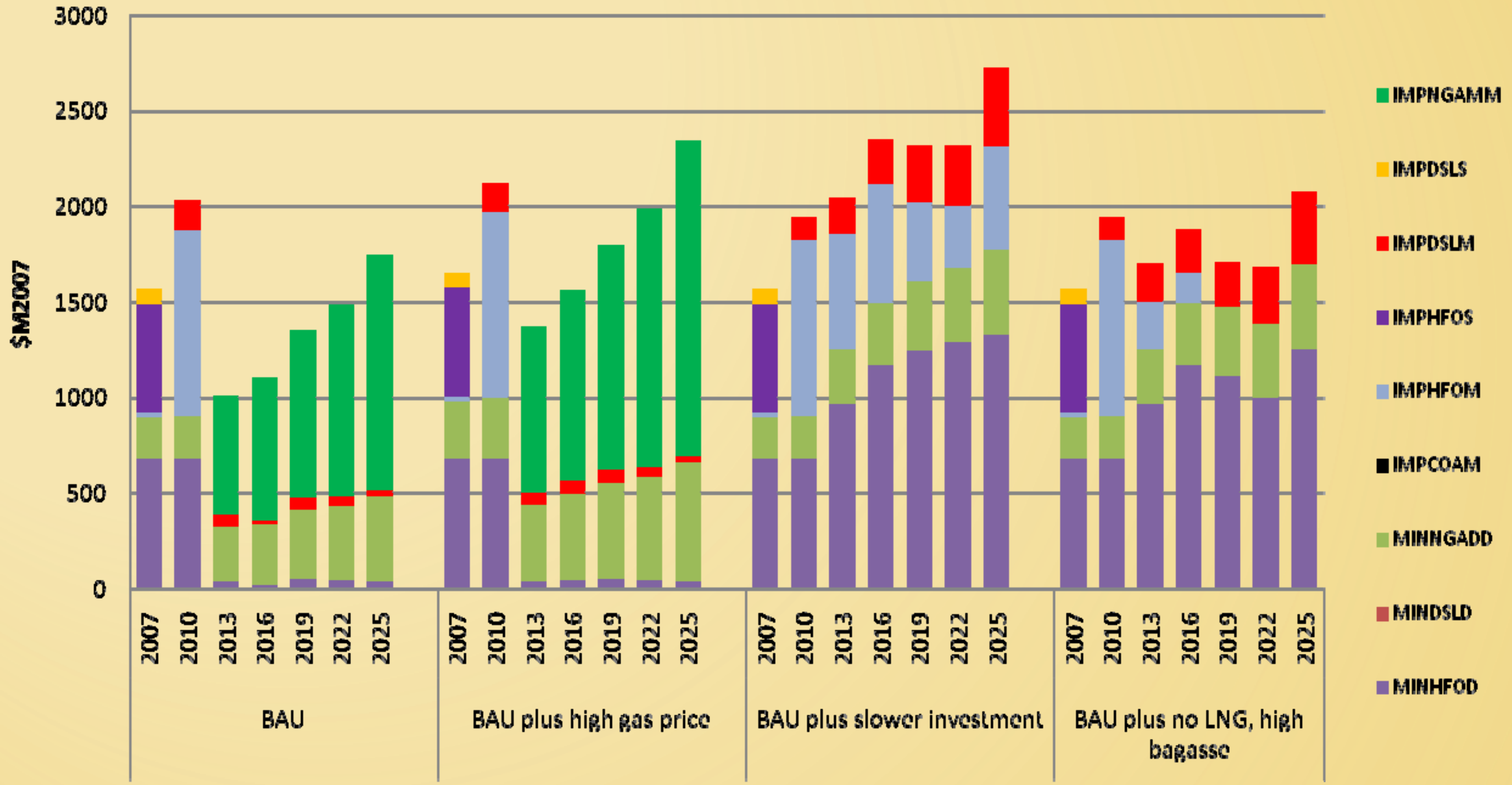
- Higher gas prices slow, but do not fundamentally alter, new investment in gas
- When the rate of new investment is constrained, investments are spread out over time
- When LNG imports are restricted, a wider variety of power plants is built, with much heavier reliance on renewables

New Power Plant Investment Spending - BAU



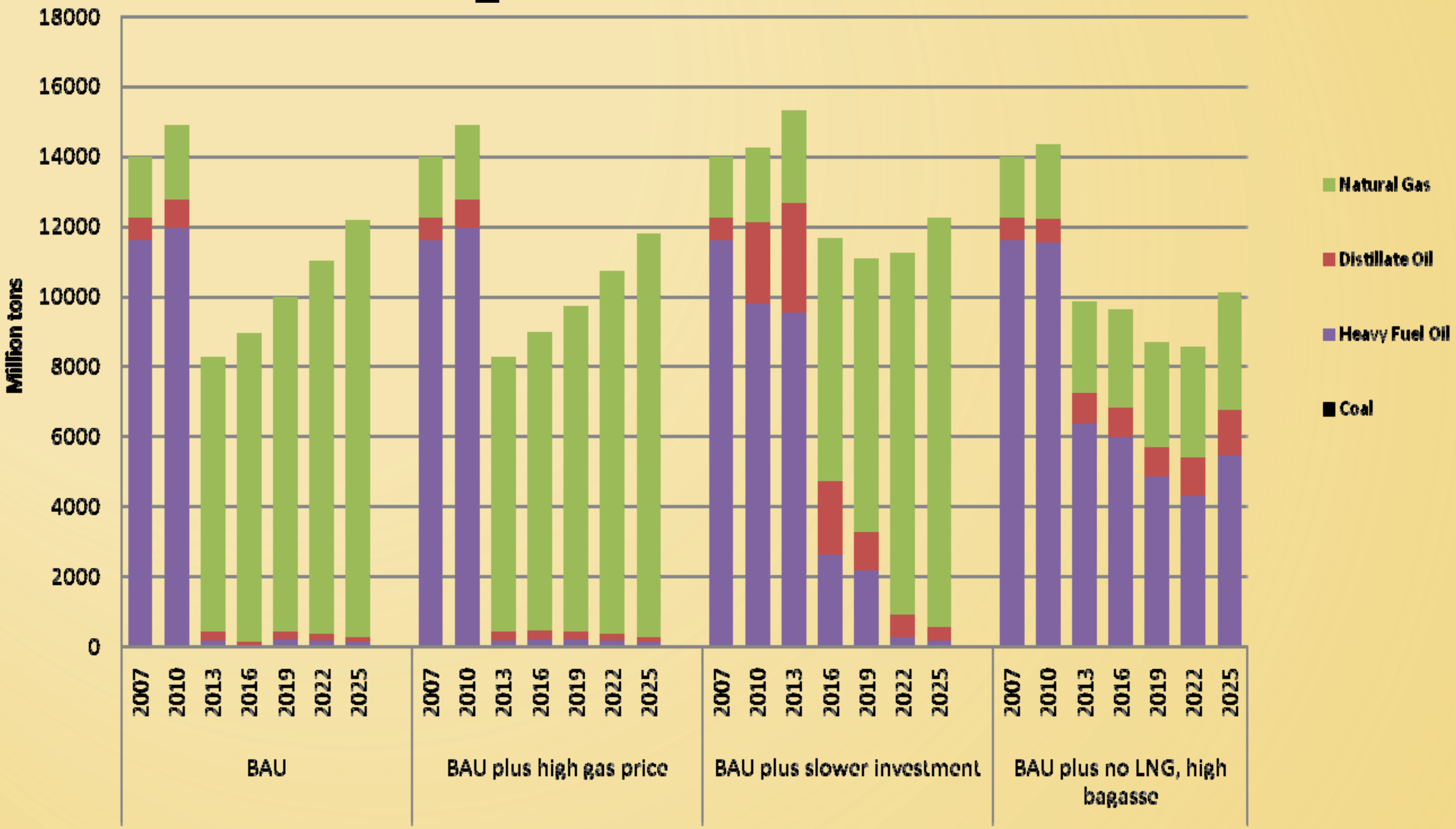
- In the unconstrained BAU cases, almost $2.5 billion investment over 2012-2014 is required to replace the existing plants
- Restricting LNG imports leads to construction of higher capital cost plants

Resource Supply Cost - BAU



- Fuel expenditures jump in 2010, as Venezuelan oil subsidies are assumed to expire.
- Switching to natural gas fired plants enables a precipitous drop in fuel costs, even in the high gas price case
- Limiting access to imported LNG greatly increases fuel costs
  - But a revitalized sugar-bagasse-to-energy industry mitigates this effect by eliminating the need for imported petroleum by 2020

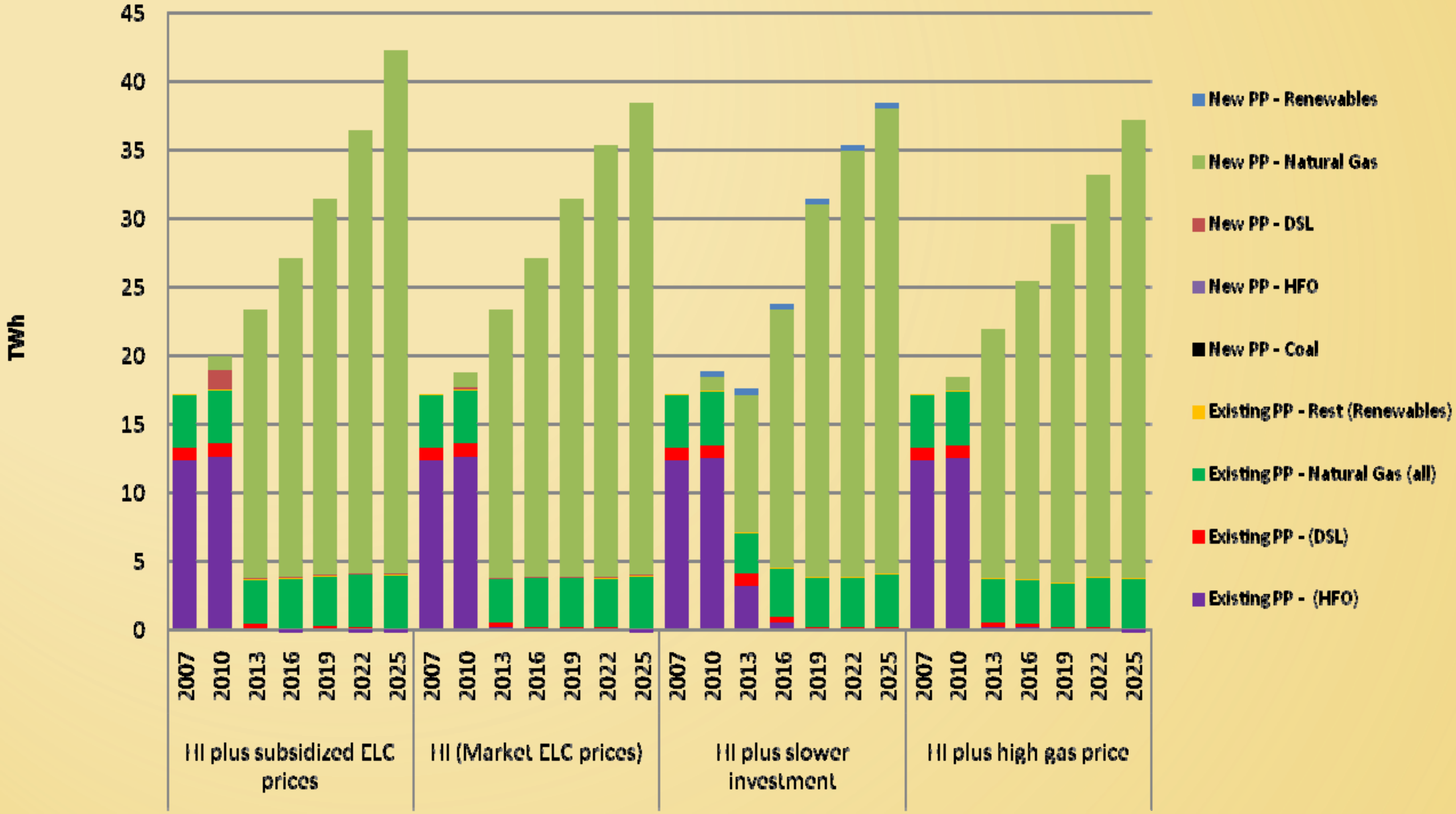
CO_2 Emissions - BAU



- Replacement of the existing plants leads to a sharp drop in CO_2 emissions.
- However, steady growth brings emissions nearly back to 2007 levels by 2025.
- Only in the renewables-heavy LNG restricted scenario are emissions flat.

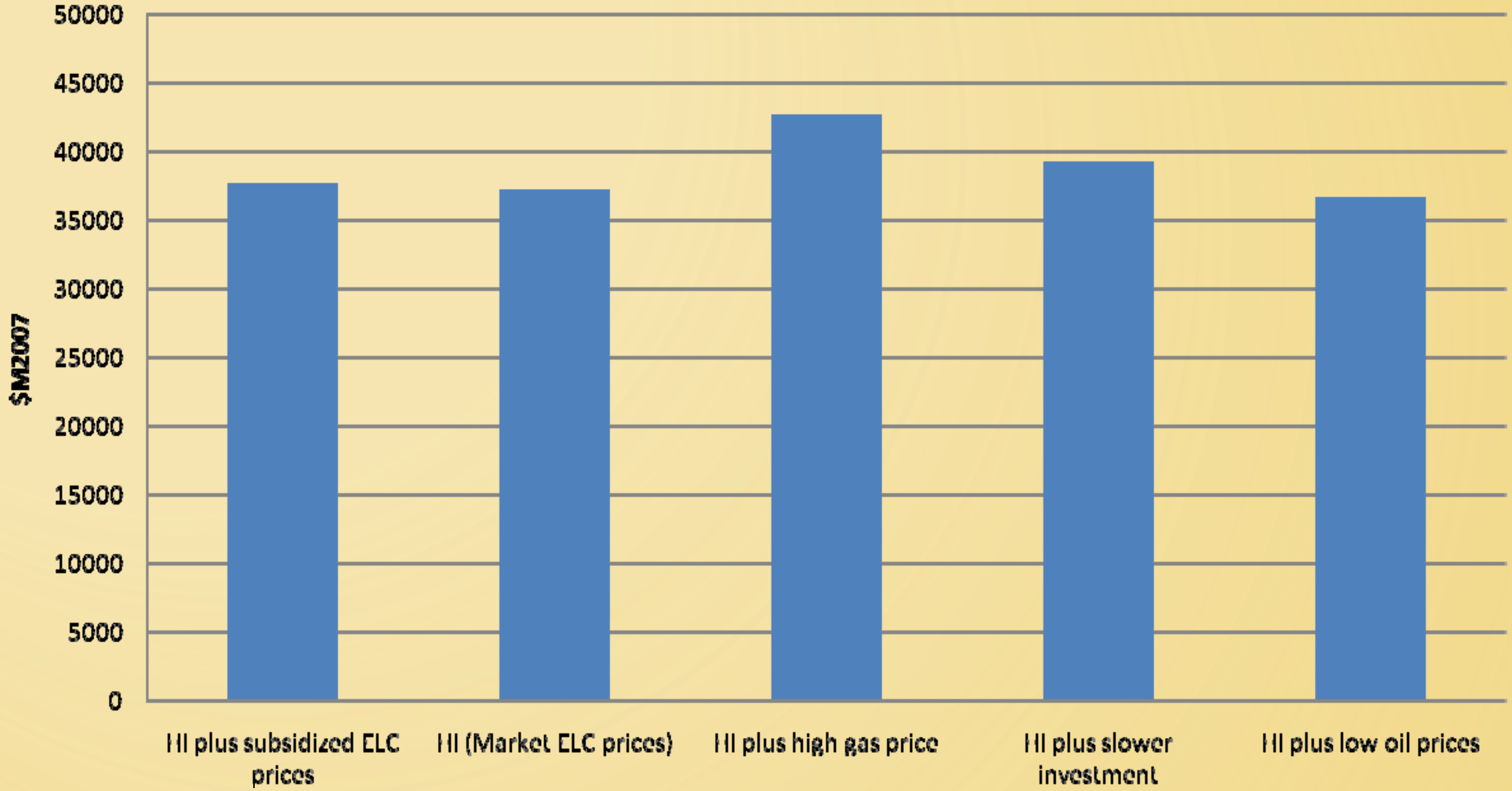
HI Scenarios

Generation by Plant Type - HI



- When subsidies are removed, demand growth moderates, but only slightly
  - The effect is most pronounced in the mid years, if the replacement of the existing plants is slowed by investment constraints

Total System Cost - HI



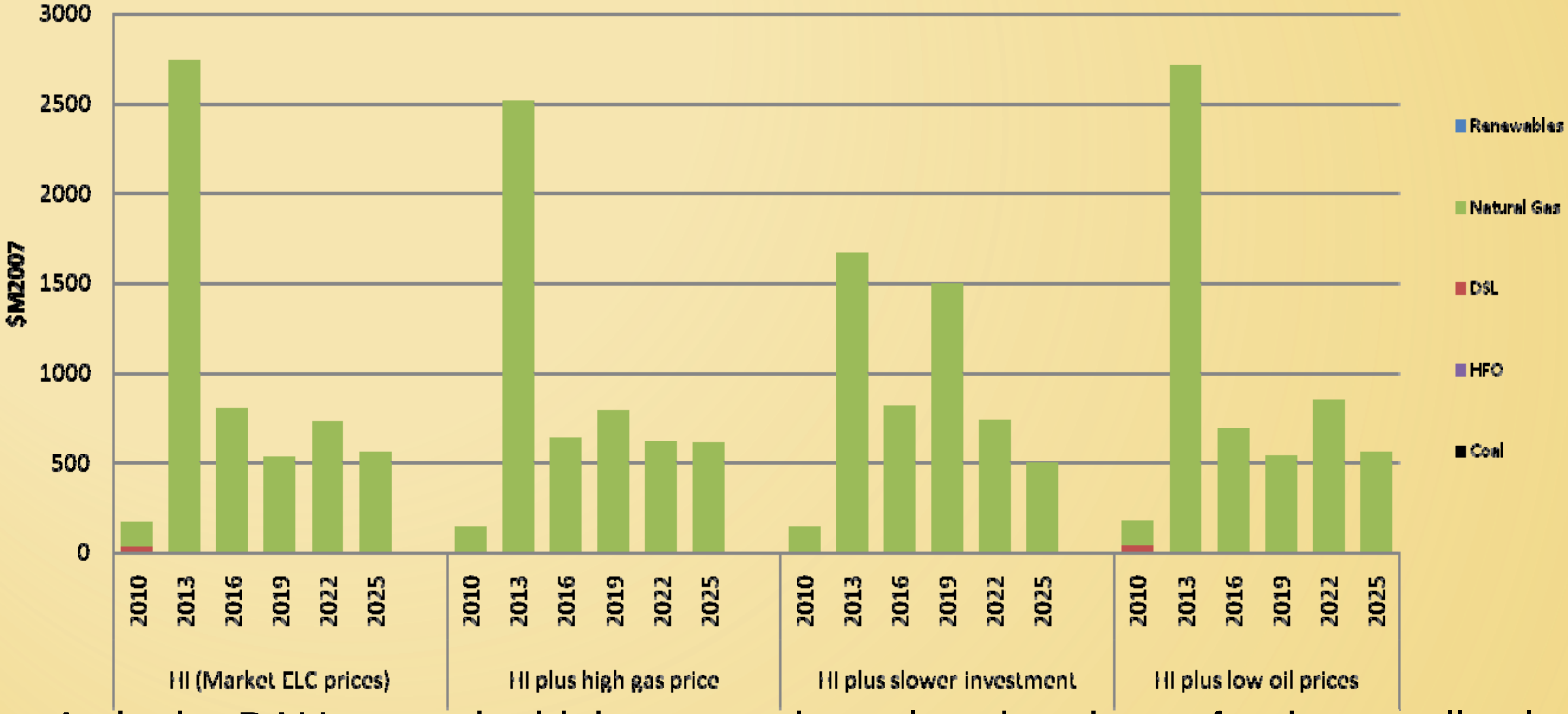
- System costs are sensitive to increases in gas prices and restrictions on the rate of investment in new power plants.
  - A 40% increase in gas prices increases system cost by 15%
- Higher domestic gas production leaves the system less vulnerable to outside conditions

Electricity Prices ($/kwh)

Scenario	2007	2010	2013	2016	2019	2022	2025
HI plus subsidized ELC prices	0.13	0.13	0.10	0.11	0.12	0.13	0.13
HI (Market ELC prices)	0.22	0.26	0.10	0.11	0.13	0.14	0.19
HI plus high gas price	0.22	0.26	0.13	0.14	0.15	0.17	0.20
HI plus slower investment	0.22	0.22	0.25	0.18	0.13	0.14	0.18
HI plus no LNG, high bagasse	0.22	0.22	0.26	0.23	0.14	0.23	0.31

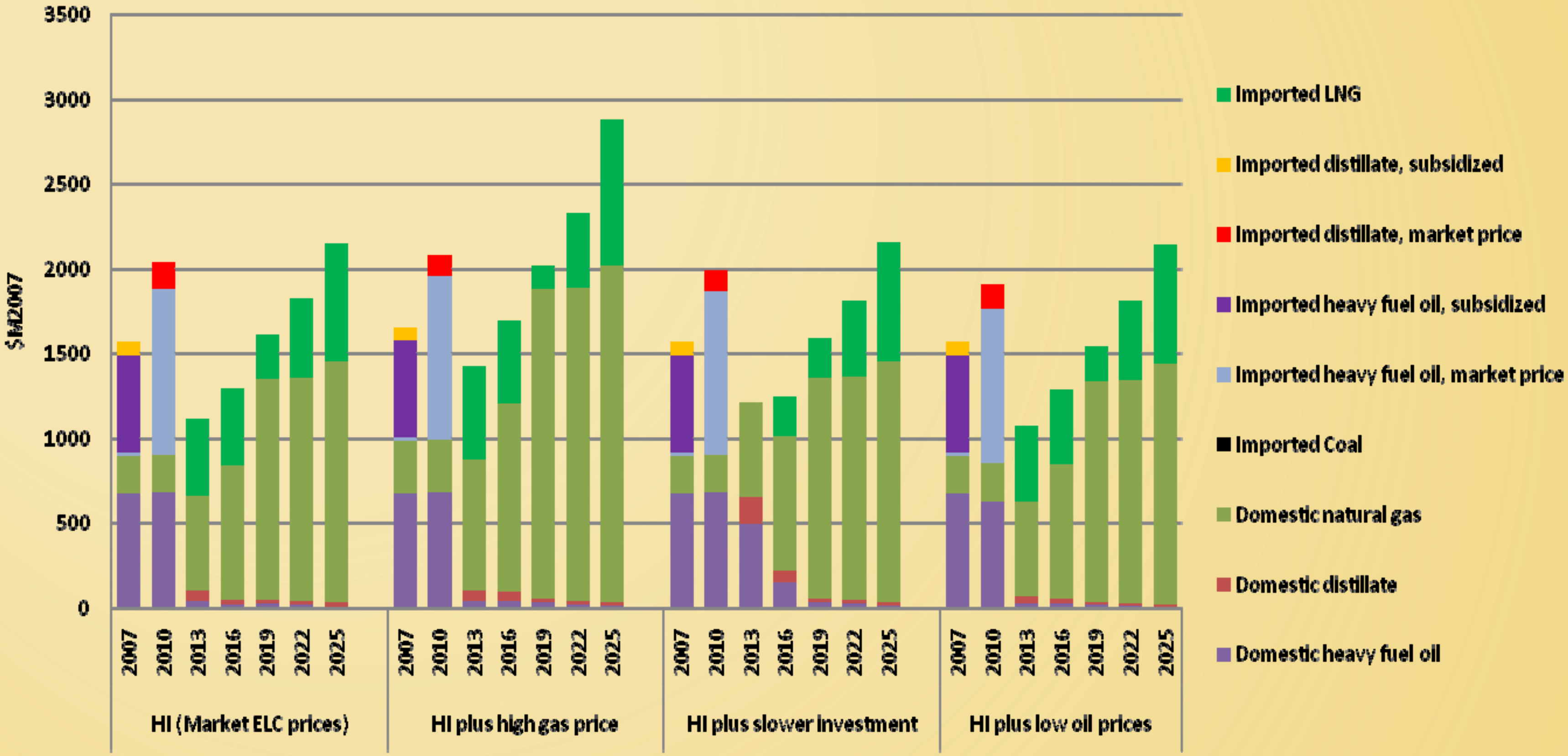
- In the subsidized case, prices are capped at estimated current unit revenue for Unión Eléctrica ($0.13/kWh)
  - This price is substantially below current costs
- With rapid investment in gas combined cycle, market prices can remain near or below this level for a decade
  - Low market prices lead to only minor adjustments in demand
- Only restriction of new investment or denying LNG imports significantly raises prices above this level

New Power Plant Investment Spending - HI



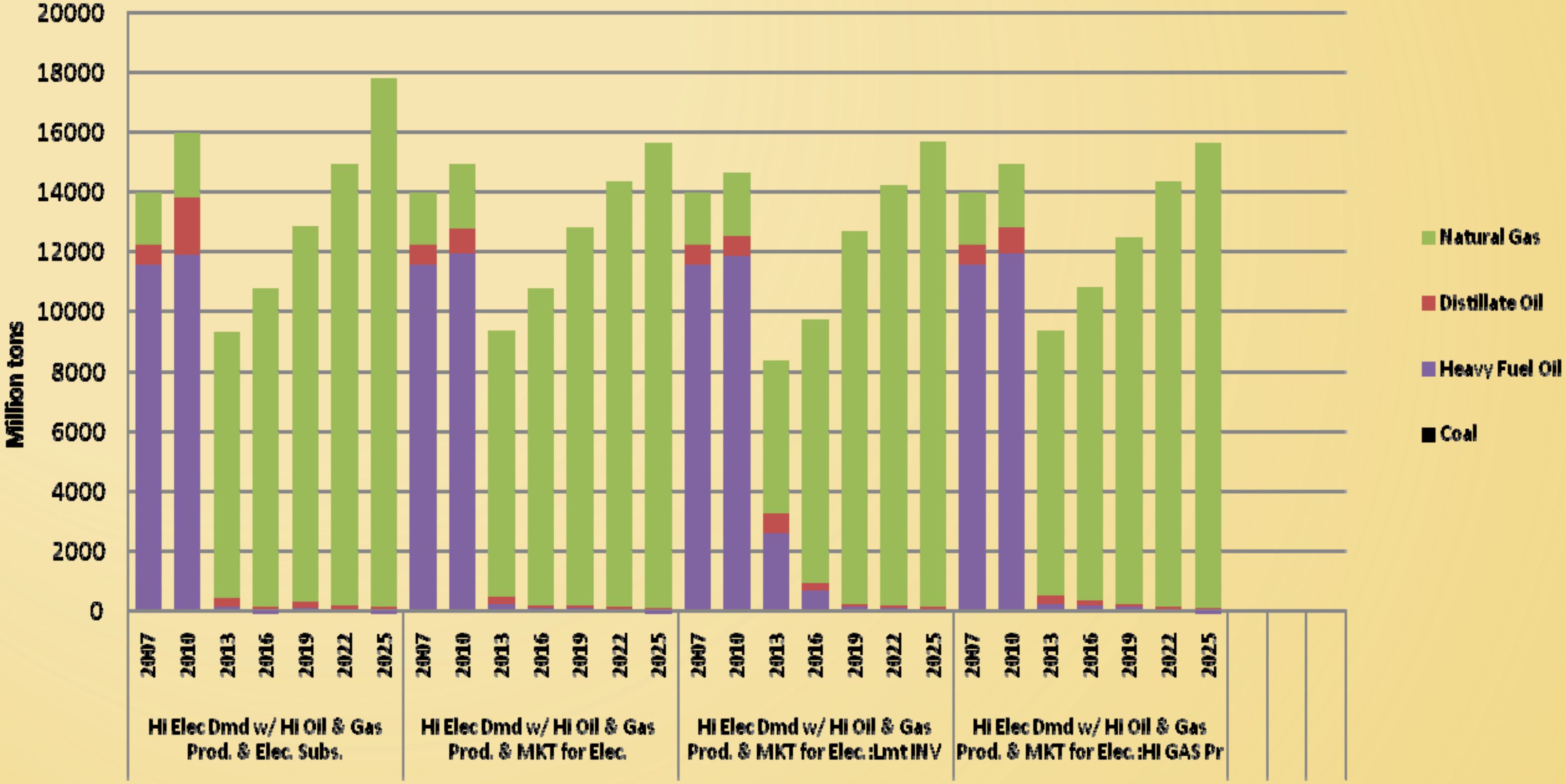
- As in the BAU scenario, higher gas prices slow, but do not fundamentally alter, new investment in gas
- With the higher rate of demand growth, more than $800 million per year is invested over the 2012 to 2014 period to replace existing plants, followed by ongoing investments of ~$200 million per year
- Further analysis could explore the impact of constraints on the feasible rate of investment

Resource Supply Cost - HI



- As in BAU, the switch to natural gas enables a substantial drop in fuel costs
- However, higher demand growth leaves the system vulnerable to increases in natural gas prices
- Higher domestic production of natural gas compared to BAU means that the system gets the majority of its fuel from domestic sources
- Postponing power system investment does not substantially increase fuel costs

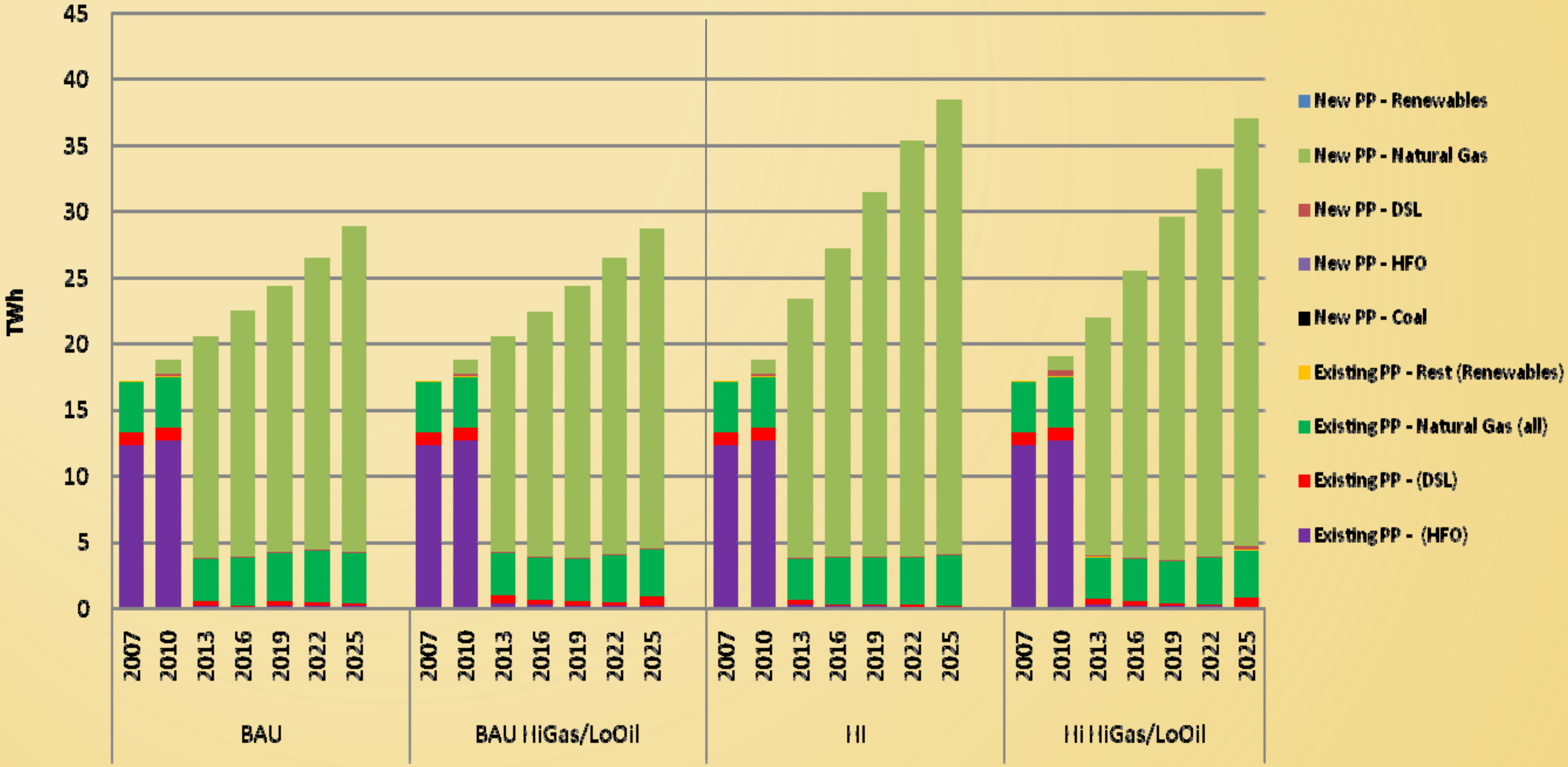
CO_2 Emissions - HI



- Replacement of the existing plants decreases CO_2 emissions by more than 40%
- However, load growth returns emissions to 2007 levels by 2025

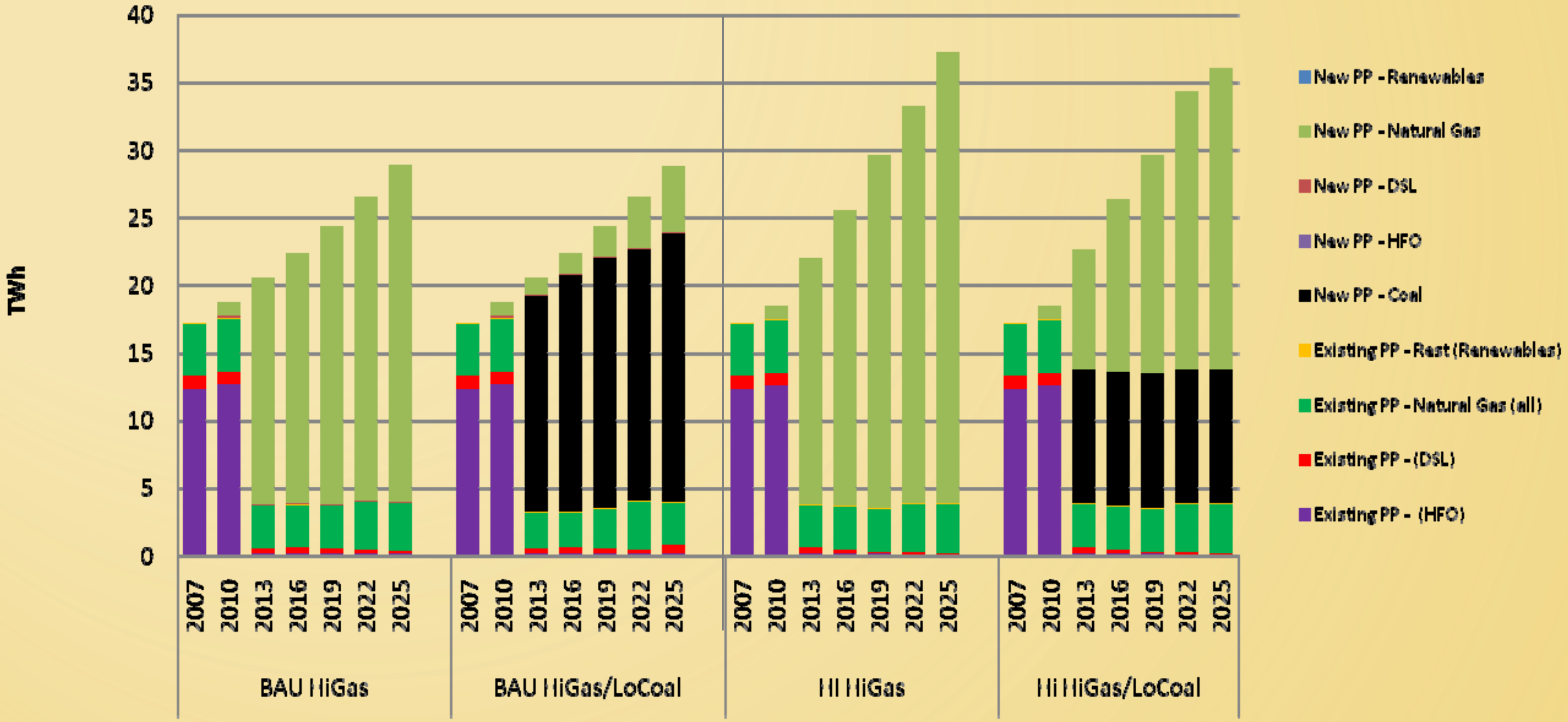
Key Sensitivities

Impact of Changing Fuel Prices on Generation Mix – Gas vs Oil



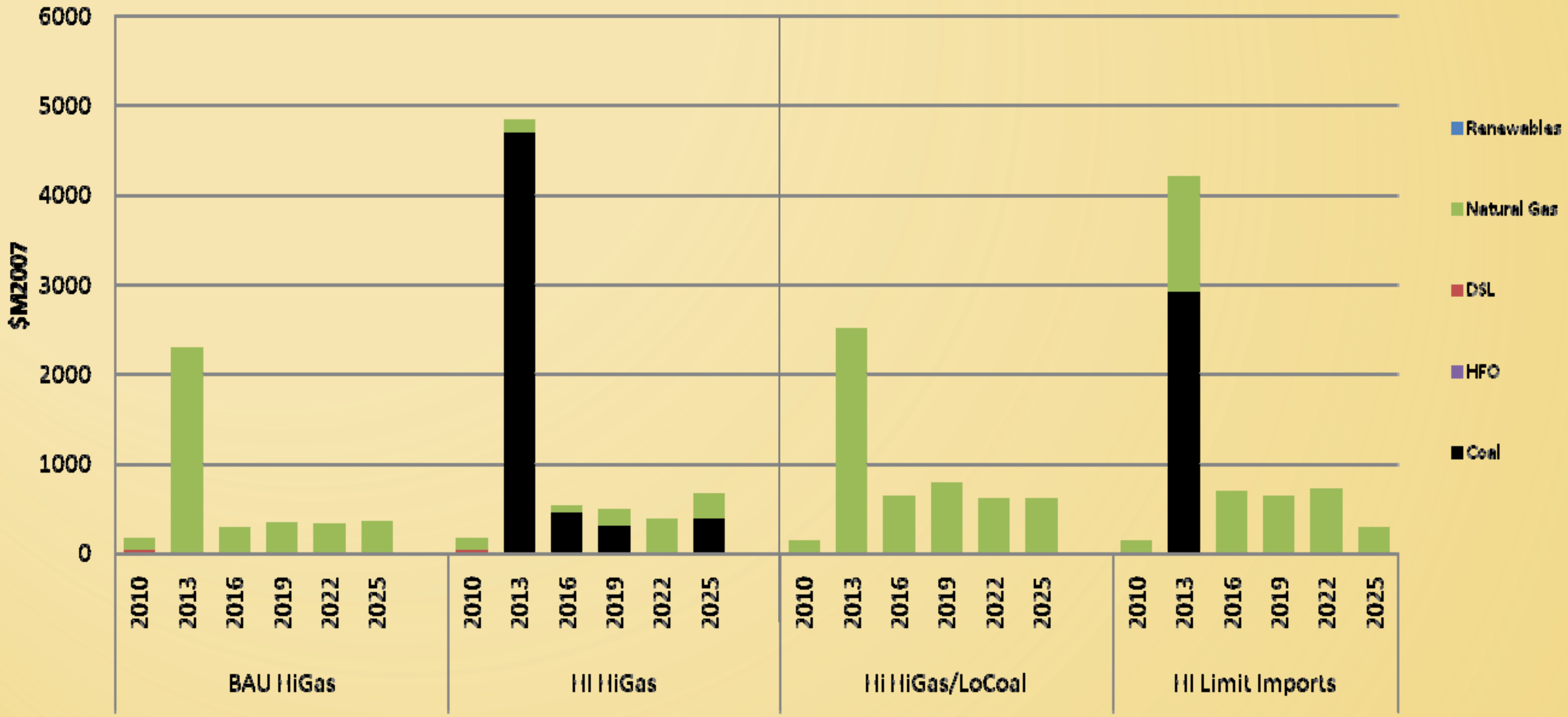
- In both the BAU and HI cases, increasing gas prices and decreasing oil prices has minimal impact on plant choice
- The natural gas fuel choice is robust to a wide range of oil/gas prices

Impact of Changing Fuel Prices on Generation Mix – Gas vs Coal



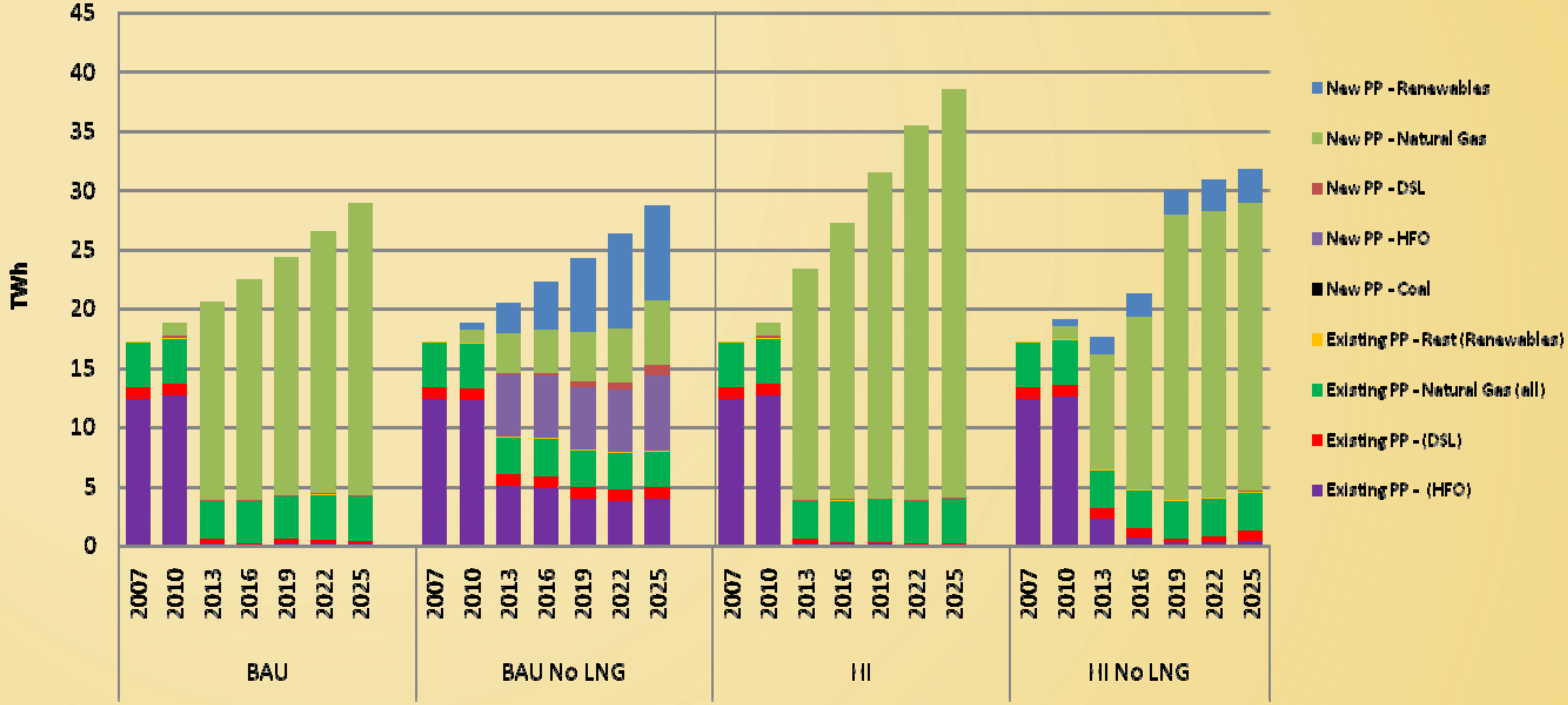
- Importing coal is not cost effective, except in the case of high gas prices. Then a 20% decrease in the assumed coal price suffices to induce replacement of imported gas.

Impact of Changing Fuel Prices on Investment – Gas vs Coal



- The substitution requires significantly greater upfront investment (but leads to lower fuel costs over time.)

Impact of Access to Gas on Generation Mix



- In the BAU case, with only moderate domestic gas production, restricting imports of LNG dramatically changes the generation mix
- In the HI case, rapidly expanding domestic gas production enables system reliance on gas even in the absence of LNG imports, with a small role for wind and bagasse
  - However, higher costs lead to a downward adjustment of demand in response to market prices, suggesting that end use efficiency potential and cost are additional important variables for study