A. ENERGY MODELING

In similar manner to the gate delay, the energy consumed in a gate can be modeled. The main sources of energy consumption are the charging and discharging capacitances – including the external load and the internal parasitic – as shown in the model below.

$$E_{gate} = E_g W_{Load} + E_p W_{gate}$$

where E_g (fJ/μm): energy factor associated with the external load;

E_p (fJ/μm): energy factor associated with the internal parasitic.

There exist other sources of energy consumption. First is that due to the crowbar current that exists when there is a direct path from supply to ground. In CMOS circuit, this current may exist temporarily during the switching of PMOS and NMOS transistors. Nonetheless, this current also depends on the output load – another source to supply (or receive) charge. Simulation shows that when signal slopes of input and output are matched, the crowbar current is negligible. Therefore, it is safe to ignore its energy.

Another source of energy consumption is from the local wire capacitance. However, most of its energy can be lumped into the parasitic energy. The remaining is considered small and neglected. Finally, leakage current also consumes energy. For high-performance designs, this energy is often insignificant compared to the active energy. So, it is ignored from the energy model.

B. ENERGY CHARACTERIZATION

The energy consumed in the gate is characterized with the same test setup as in the delay case. The results for common gates are summarized in Table 1. Notice that the terms E_g and E_p of dynamic gates are larger compared to those of static gates due to (i) the presence of the keeper circuit that fights against the pull-down of the NMOS network and (ii) the larger diffusion capacitance on the pull-down path.

Table 1. Energy characterization of common gates

	Static		*Dynamic*	
Gate	E_g (fJ/μm)	E_p (fJ/μm)	E_g (fJ/μm)	E_p (fJ/μm)
INV	2.32	4.46	2.80	8.56
NAND2	2.87	3.36	3.14	8.01
NAND3	2.86	4.34	3.31	7.86
NAND4	-	-	3.48	7.86
NOR2	2.77	5.15	2.80	8.88
NOR4	-	-	3.36	13.3
OAI	1.90	4.47	3.08	11.1
AOI	2.95	4.15	3.14	8.18