Bureau, 2003). Small amounts of copper, tin, and lead are also die cast (US DOE, 1999). Die cast aluminum parts are in demand by many industries, and its relatively low cost and light weight ensure that it will be the dominant metal in the field for years to come.

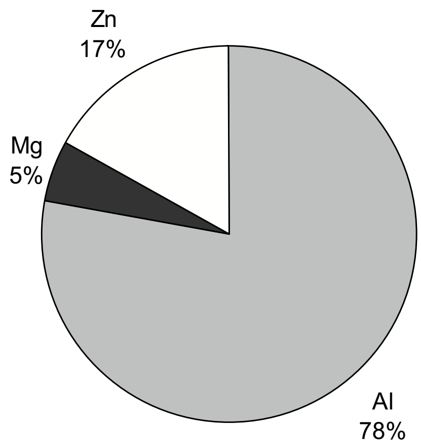

Figure 4. Metal distribution of US die casting in 2003. The total amount of die cast metal was 2.03 million tons. Source: Schifo and Radia, 2004.

A representative aluminum die caster uses bout 28% scrap metal by mass. The remainder, based on US Census Bureau data (US Census Bureau, 2003), is new material. Higher quantities of new metal allow greater control over alloy contents and reduce the metal loss due to dross formation. Scrap metal is prone to increased dross formation because the scrap is predisposed to being contaminated with lubricants which burn off, creating an oxidizing environment in the furnace around the lubricant and flux. As much as 80% of dross comes from the melting of scrap metal. Additional metal loss occurs when raking dross from the top of a furnace, for a total direct metal loss around 5% (Roberts, 2003a).

Reverberatory furnaces are the most common type of furnace used in aluminum die casting foundries. Reverberatory furnaces use wall mounted burners to radiate heat from the refractory wall to the metal inside. Though typically fired by natural gas, electric reverberatory furnaces are available, and are primarily used as holding furnaces. Many foundries have more than one furnace – one used for melting metal and another for holding molten metal. The same types of furnace can be used for both purposes, but furnaces that are designed for efficient melting are less efficient at holding molten metal (Upton, 1982). Other techniques allow optimization of furnaces for the two functions. For example, it is recommended to keep melt furnaces at near capacity for efficiency.

Energy requirements for holding furnaces are typically much lower than for melting furnaces, simply due to the high energy requirements of melting metals. An average melting furnace like that in Table 1 has an efficiency around 40%, requiring 2.5 times more than the theoretical minimum to melt the metal (Dalquist and Gutowski, 2004). This is in agreement with other published gas-fired furnace efficiencies for melting aluminum (Broadbent, 1991).

	MJ/kg	m^3 natural gas/kg
Melting furnace	2.465	0.08
Holding furnace	0.493	0.02

Table 1. Natural gas use per kilogram aluminum cast for a typical melting and holding reverberatory furnace in an aluminum die casting foundry. Source: Bergerson, 2001.

Overall, natural gas fired furnaces are much more common than electric furnaces in die casting foundries. Despite lower efficiency at the plant (Broadbent, 1991), variable costs for natural gas are markedly lower than for electricity (EIA, 2002). 2002 energy use in aluminum die-casting foundries topped 10 million MWh, 85% of which was consumed as natural gas at the plant (Census Bureau, 2003). The remainder was consumed as electricity produced off-site (does not include losses in electricity generation and distribution). Much of that electricity was not even used in melting, but rather in other parts of the process with smaller tools and in auxiliary functions like administration.

The consumption of raw energy for melting causes emissions to the environment. Though gas-fired emissions are released at the foundry (Table 2), it is cleaner than electric-fired melting from the national grid when compared at the life-cycle scale.

	Fuel-fired	Electric
CO2	147 – 294	495
SOx	0.001 – 0.0015	2
NOx	0.175 – 0.35	1
VOCs	0.005 – 0.015	unknown
Particulate	0.0	unknown

Table 2. Emission factors for gas-fired and electric melting furnaces in kg/tonne. Electric emissions are based off the proportion of different energy sources on the US grid. Gas-fired emissions are based on data from US DOE, 1999.

Electric-fired furnaces would have to be penalized for electricity losses at the plant, such that the 2,958 kJ for melting and holding 1 kg of aluminum would require approximately 9,000 kJ at the plant (EIA, 2001). Emissions would vary by the source of the electricity, but based on the distribution of US energy generation (EIA, 2000), a MJ of electricity is accompanied by the generation of 167 g of CO_2, 0.7 g of SO_2, and 0.3 g of NO_x (EIA, 2002). Therefore, the melting and holding of 1 kilogram of metal for casting would result in the emissions of 495 g CO_2, 2 g SO_2, and 1 g NO_x.

CASTING

The high-pressure die casting process can be done in two different types of machines, known as hot-chamber and cold-chamber. Cold-chamber machines (Figure 5) are typically used for high-temperature metals such as aluminum and magnesium alloys. The die halves are first locked into the machine and the plunger retracted, as the molten metal is ladled into the shot chamber by way of a pouring hole. The plunger is moved back into the chamber, forcing the metal into the cavity. It remains in place and under pressure for the duration of the "dwell time" required to solidify the metal. After the metal solidifies, the die is opened and plunger returned to its initial position.