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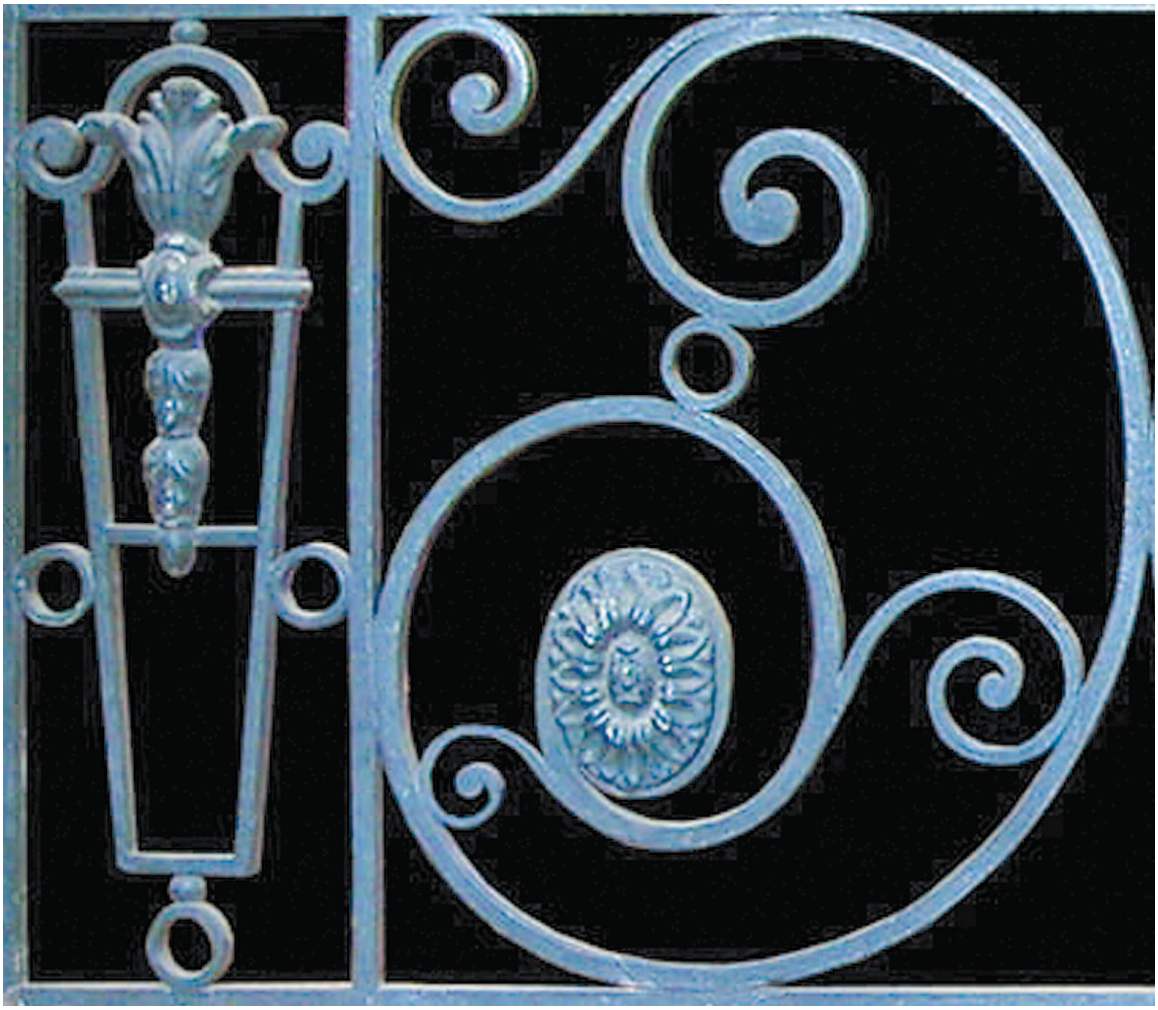

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In-Use Stocks of Iron in the State of Connecticut, USA

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ABSTRACT

A "bottom-up" study was conducted for in-use stocks of iron in the State of Connecticut for the base year of 2000. The study covers 145 product types in the four major categories of transportation, buildings, equipment, and infrastructure. The method of calculation, as well as the allocation of iron in different use categories is discussed. The total result of 9,300 kg of iron per capita is slightly higher than that from a previous study for the city of New Haven, but below the results of national top-down analyses. Possible reasons for these discrepancies are considered. A sensitivity analysis and an error rating were applied to the calculations to examine uncertainties.

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1. INTRODUCTION

Iron is by far the most widely used metal on Earth, surpassing the use of all other metals by a factor of 10 (Kesler 1994). While different societies use metal for different applications, in general it is present in most technological objects in the modern world. As such, the amount of iron in a particular area can serve as a proxy for that area's level of development, particularly in the industrial sense of the word. Müller *et al.* (2006) showed that the per capita in-use stock of iron has leveled off in the United States since the mid 1980s and extended their analysis to other OECD countries are extending their analysis to other countries to see whether or not this is a universal phenomenon. If so, this so-called saturation level of iron could serve as a benchmark by which to measure the progress of developing economies. By making accurate estimates of in-use iron stocks, we can understand the material requirements of countries as they develop along a path toward iron saturation.

"In-use" refers to metal that is currently providing services to people. Abandoned buildings, derelict bridges, junked cars, and other products that have reached the end of their lives but have not yet entered waste management are not considered. On the other end of the life cycle, products in showrooms and other commercial establishments that are for sale or are being produced in manufacturing facilities are also not considered in the present study.

Several studies have attempted to quantify in-use stocks of iron, most utilizing a top-down economic analysis to arrive at their results. These top-down analyses are the type favored by government institutions such as the United States Geological Survey (Sullivan 2005). Bottom-up studies of iron stocks have also been performed, notably for the cities of Beijing, China (Wang 2006) and New Haven, Connecticut, USA (Drakonakis *et al.* 2007). Since these analyses focus on urban centers, they are not necessarily representative of the national picture. They also fail to include any industry or piece of infrastructure that happens to be outside city boundaries. The present study evaluates in-use stocks over the larger geographic entity of the state of Connecticut in an attempt to find a more accurate reflection of the national average.

2. INDIVIDUAL RESERVOIR METHODS AND RESULTS

Each of the four major categories – transportation, buildings, equipment, and infrastructure – was separated into many subcategories or product subcategories, as detailed below. In general, in order to make a calculation of in-use stock, it was necessary to find three pieces of information:

1. The number of a certain product existing in Connecticut (i.e., microwave ovens);
2. The average weight of a product of that type;
3. The iron (ferrous) content of a product of that type.

These factors were then multiplied to find the total iron stock for that category. Data were taken from government and published sources where possible. Where official data were lacking, the values given are informed estimates and are specified as assumptions. We list the results without attempting to specify the number of significant figures. The assumptions and uncertainties that were involved, however, indicate that two significant figures are appropriate in most cases.

Due to varying degrees of data availability on the state level, data were not prevalent enough to derive an estimate specific to the year 2000. In general, where year 2000 data were lacking, data averages over the decade 1996-2005 were used. In a few cases, data were available for only a single year within this range.

2.1 TRANSPORTATION

This category includes all vehicles used to carry people and goods. Cars, trucks, planes, and trains are counted here, but not the infrastructure that they require. So, for example, rolling stock is counted but the physical rails are not. We also include non-resident transportation stock, which includes vehicles not owned by people or companies in Connecticut but that nonetheless spend time within state boundaries. This non-resident stock is in the form of visiting barges, airplanes in transit, or commuter vehicles. In general the non-resident stock calculations were made by considering the annual fraction of time that a vehicle spends within state boundaries.

2.1.1 Automobiles

The Bureau of Transportation Statistics (BTS) published the number of cars registered in Connecticut. Typical car weights were taken from Ward's Motor Vehicle Facts & Figures and the Center for Sustainable Management at the University of Michigan (online at http://css.snre.umich.edu/css_doc/CSS01-01.pdf) and then averaged to get a weight factor. The average ferrous content of cars was found for the years 2000, 1999, 1991 and 1985, while the average lifetime of a passenger vehicle is 14 years (Ward's Communications 2002). Using these data, a weighted average ferrous content of 70% was calculated for cars.

The Federal Highway Administration (FHWA) provided the number of private, public, and commercial light trucks, separated by vehicle type (pickup, SUV, van, etc). The Center for Transportation Analysis (CTA)'s Engineering Science & Technology Division published weight ranges for these different types of light truck. The ferrous content of light trucks was assumed to be the same as that for cars.

The number of medium and heavy trucks (including farm tractors and truck tractors) was found from the 2002 Economic Census for Connecticut, the FHWA, and Ward's Automotive Yearbook 2004. The Economic Census also published data on the relative percentage of each weight class, giving an accurate weighted factor for the mass of a typical medium or heavy truck. An Environmental Product Declaration by Volvo was used as the basis for the ferrous content of medium and heavy trucks, namely, 78%.

BTS provided numbers for registered commercial semi-trailers and car or farm trailers. Typical weights of these trailers were found on online auctions. Although many semi-trailers incorporate a significant amount of aluminum in order to reduce tare weight, the ferrous content was assumed to be equal to that of medium and heavy trucks, for lack of other data.

BTS was the data source for bus registrations as well. The weight of a Connecticut Transit bus was taken to be representative of all buses. Again, the ferrous content was assumed to be equal to that of medium and heavy trucks.

The number of registered motorcycles in the state is published by BTS. The CTA gives the number of registered (and estimated non-registered) snowmobiles in Connecticut (Davis *et al.* 1999), while the Connecticut Department of Environmental Protection (CT DEP) gives the number of registered all-terrain vehicles (Lewis 2005). The average weight of each of these vehicles was determined from interest group websites. Due to lack of data, the ferrous content of each of these vehicles was taken to be equal to that of cars.

For non-resident vehicles, only cars and trucks were considered. The CT DOT provided data on the number of vehicles traveling into and out of the state daily. Though many Connecticut residents commute into New York, the net balance of non-resident cars is positive by nearly 20,000 vehicles. The percentage of cars versus light trucks is assumed to be equal to those derived from vehicle registrations. Assuming that each vehicle is within Connecticut borders for ten hours per day, five days per week, the resulting 50 hours was divided by 168 to find the weekly fraction of residence. This fraction was then multiplied by the fraction of cars or light trucks, the average vehicle weight and the percent iron (as above) to find the iron stock of cars commuting into the state.

Data on shipping by truck were collected from the BTS as reported in the 1997 U.S. Census Commodity Flow Survey, by weight of shipment. These total weights were divided by 15 tons, the average truck weight derived from a report on freight traffic (Beagan and Grenzeback 2002), to get the number of truck trips. Trucks that delivered goods to or from Connecticut were assumed to stay over for one day and to be on state highways for one hour. Data were also collected on the truck traffic between the other New England states and the Atlantic Coastal states, under the assumption that these trucks would drive through Connecticut. These trucks were assumed to make the journey across the state in 2.5 hours. The total number of truck-hours in Connecticut was divided by the annual total and then multiplied by the typical weight of a tractor trailers and the ferrous content factor of 77.7% (as above) to find the non-resident iron stock in shipping trucks.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Automobiles	**5,637,820**	**1,655.5**
Cars	2,103,770	617.7
Light Trucks	2,306,566	677.3
Specialty and Large Trucks	701,084	205.9
Trailers	370,960	108.9
Buses	99,506	29.2
Motorcycles, Snowmobiles, ATVs	9,270	2.7
Non-resident	46,664	13.7

2.1.2 Bicycles

The stock of bicycles in the state was calculated using a product lifetimes approach. The average age of a bicycle is 14 years (Rostkowski *et al.* 2007). National sales of bicycles were found for the years 1992 to 2000; sales in earlier years were assumed to be equal to those of 1992 (National Bicycle Dealers Association, online at http://nbda.com). The number of bicycles was calculated by summing total sales over the product lifetime and scaling by population to Connecticut. A typical bicycle weight was assessed from moving estimates. It was assumed that 75% of bicycle sales were steel-framed bicycles and that 80% of the weight of these bicycles is steel makes up to 80% of the weight of these bicycles.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Bicycles	8,818	2.6

2.1.3 Air

The Federal Aviation Administration records the number of all types of aircraft registered in Connecticut, including single, double, and jet engine planes, helicopters, military aircraft, gliders, and ultralights. Typical weights of planes were found in online articles and commercial specifications, helicopter weights from the National Transportation Safety Board, and glider and ultralight weights from an online bulletin board. The average ferrous content of aircraft is only 10%, as most of the structural metal is aluminum.

Considering non-resident stock of aircraft, the BTS reports that 47,479 airplane departures occurred in Connecticut in 2000. It was assumed that each plane is on the ground for an average of five hours, which includes those planes that berth overnight. Multiplying these two numbers together and dividing by the number of hours in a year gives the (hypothetical) number of non-resident planes on the ground in the state at any one time. The typical weight of a commercial jet was assessed from Delta's Comair service. These two numbers were multiplied by a 10% ferrous concentration to find the iron stock.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Air	556	0.2
in CT	502	0.1
Non-resident	54	0.0

2.1.4 Marine

Motorboat and sailboat registrations were collected from the BTS. It was assumed that 85% of registered boats are strictly motorboats, while the remaining 15% are sailboats. The weights of such boats were collected for vessels greater and less than 24 feet in length from a variety of boating catalogs. These were then averaged to get appropriate factors for each class of boat. It was assumed that 70% of sailboats are steel or iron, while the ferrous content of motorboats is 85%.

The city of New Haven has two commercial portage companies: Gateway Terminal and Buchanan Marine, with a total of 16 tugboats and 34 barges in residence. As New

Haven harbor handles close to half of all shipping traffic in the state, it is estimated that there are 32 tugboats and 68 barges in residence in Connecticut ports. In addition, Buchanan Marine owns 250 barges that operate outside the state that were included as resident stock. The BTS and the Connecticut Department of Transportation (CT DOT) report on the number of ferries in the state. Intrastate ferries were counted as fully resident, while interstate ferries (such as that from Bridgeport to Port Jefferson, NY) were counted as half-resident. Some ferries also make use of tugboats, which were added the tally above. Typical weights for tugboats and barges were given by Buchanan Marine Inc. as reported by Drakonakis *et al.* (2007). The U.S. Military's Defense Re-utilization and Marketing Service reports a typical ferry weight of 220 tons. Again with guidance from Buchanan Marine, the typical ferrous content of marine vessels was assumed to be 95%.

Considering commercial boats, the Center for Marine Social Science at the Massachusetts Institute of Technology published data on the number of fishing boats in different coastal towns in Connecticut. These are disaggregated by type, including trawlers, lobster pots, gillnets, and others. The weights of these different boat types were found from online sources, with the "other" category being assigned the average. Fishing boats were assumed to have a 90% ferrous content.

The military submarine base in Groton represented a large, stock of iron; data on the number, type, and weight of submarines there were gathered from military history documents published on the Naval Submarine Base New London website (online at http://www.subasenlon.navy.mil/history.htm). As with other ships, the ferrous content was taken to be 95% for all submarines.

Non-resident ships were in the form of tankers and dry cargo ships offloading into various ports. The Institute for Water Resources of the U.S. Army Corps of Engineers collects and publishes the trips and drafts for each port in the country. Data for incoming vessels were collected for each port in Connecticut, categorized as "Passenger/Dry Cargo," "Tankers," and "Tugs." The first category was adjusted for the number of ferry trips, which were collected from each ferry company and subtracted from the total. The U.S. Coast Guard reported the weight of a typical tanker. The BTS has a database of all bulk solids cargo ships registered in the country. The average weight of these registered ships was used for calculations. As above, the iron and steel content of these ships was assumed to be 95%. Each ship was assumed to have a residence time of three days, which was divided by 365.25 to find the annual fraction of residence. This was multiplied by the total number of trips and drafts, the typical weight, and the ferrous content to find the non-resident marine iron stock.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Marine	**1,059,384**	**311.1**
in CT	379,026	111.3
Non-resident	680,358	199.8

2.1.5 Rail

The Association of American Railroads (AAR) reports that Connecticut has one "Class I" railroad, two regional railroads, and five local railroads. There are also two passenger rail companies, namely Amtrak (including the Shore Line East commuting service) and Metro North Railroad. Data on the number and type of railcars for Metro North and Shore Line East were collected from CT DOT. The local railroads were contacted to find the number of locomotives operating in the state and the average length of each freight train. In addition, there are three railroad museums in Connecticut, which have a combined total of 29 locomotives on display. Typical weights were collected for railcars (Vantuono 2000), electric units (Citytrain, online at http://www.citytrain.com.au/about/fleet/emu/emu.asp), push-pull units (Danger Ahead, online at http://danger-ahead.railfan.net/reports/rep2001/selby20010228_rs.html), and diesel locomotives (Trinity Railway Express, online at http://www.trinityrailwayexpress.org/trerollingstock.html). All were considered to have a ferrous content of 95%, based on a quote from the CT DOT Rail Division.

Rail lines with yards outside of the state but still operating within state boundaries were considered non-resident. In each case, the hours that each train spends within Connecticut was assessed from published weekly schedules. These figures were divided by 168 hours to get the weekly fraction of residence. This was multiplied by the total number of cars in each train (as above), their typical weights, and a ferrous content of 95% to find the non-resident mass of iron in rail cars.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Rail	**37,323**	**11.0**
in CT	34,051	10.0
Non-resident	3,271	1.0

2.2 BUILDINGS

Buildings are the largest common man-made structures, and in general, they represent vast repositories of in-use iron stocks. Steel is used to frame many buildings and is present in the nails of wood-framed buildings. In this category we also consider iron that acts in various building systems, such as piping or HVAC ductwork.

2.2.1 Residential Structures

The 2000 U.S. Census collected and published data on the number of residential housing units for each state, by the size of the building. The average floorspace of each type of building was extrapolated from calculations using detailed records from the City of New Haven Tax Assessor's Office, which provided information on the size and type of every building in the city. These city averages were assumed to hold true for buildings across the state. Multiplying the two numbers gave the total residential floorspace in Connecticut. For the purpose of this study, it was crucial to know the dominant framing and exterior wall materials used for framing and construction of building structures. It was assumed that all 1-2 unit homes are wood-framed, 10% of 3-4 unit houses are masonry, 50% of 5-9 unit houses are masonry, 80% of 10-19 unit buildings are masonry, and that any building with more than 19 units is steel-framed concrete or masonry. The average square footage of mobile homes was taken from the U.S. Census 1996 American Housing Survey for Hartford.

For wood-framed buildings, the iron in-use stock includes the iron in nails, pipes, fixtures, and other elements of the house. Three LCA studies were found that specified material flows during the construction phase of residential buildings (Blanchard and Reppe 1998; Bowyer *et al.* 2002; Fay *et al.* 2000). An average of 0.75 kg of iron per square foot was established thus established for wood-framed buildings. For masonry and steel-framed buildings, two estimates were made and then averaged. The first was based on consultations with Chinese universities, architecture firms, and construction firms (Wang 2006). The second used steel intensity factors for buildings with different exterior wall types (Seo and Hwang 1999). Mobile homes and trailers were assumed to have four kg iron per square foot.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Residential Structures	**3,778,236**	**1,109.4**
Single Family	1,726,665	507.0
Multi Family	477,786	140.3
Apartment Buildings	1,560,121	458.1
Trailers	13,664	4.0

2.2.2 Residential HVAC

Information on the numbers and types of household HVAC equipment was found in the U.S. Census 1996 American Housing Survey for the Hartford Metropolitan Area. This included furnaces, boilers, air conditioners, heat pumps, heating stoves, electric heaters, and water heaters. These numbers were then extrapolated for the entire state. Connecticut also has a large stock of older homes that still use cast iron radiators. It was assumed that this represents five percent of the housing market and that each house has eight radiators. Typical weights of all residential HVAC units were found from manufacturer specifications (Ingram's Water and Air Equipment; Columbia Boilers; Hammerzone; General Electric; AC Direct; Sears; Paladin Radiators). The ferrous content of air conditioners has been thoroughly researched and is reported to be about 46% (Nakamura and Kondo 2001). Assumptions were made for the other HVAC units: 60% ferrous content in a hot water heater; 95% ferrous content for furnaces, boilers, heat pumps, and space heaters; 100% ferrous content for cast iron units such as heating stoves, fireplaces, radiators, and oil tanks.

It was assumed that all housing units with fireplaces also had chimney liners, which are typically made of stainless steel. The thickness of these liners was taken from a study on nickel (Rostkowski *et al.* 2007), the average height of a chimney was calculated using the City of New Haven Tax Assessor's property listings, and the length of a chimney side was assumed to be 0.5 meters. Stainless steel is taken to be 74% iron throughout. The total volume of chimney liners was multiplied by the density and ferrous content of stainless steel to find the mass of iron.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Residential HVAC	**369,702**	**108.6**
Heat Pumps	3,108	0.9
Gas-fired Furnaces	37,671	11.1
Oil-fired Boilers	116,888	34.3
Oil Tanks	98,828	29.0
Built-in Electric Heaters	4,370	1.3
Wood Stoves	2,867	0.8
Central Air Conditioning	12,701	3.7
Radiators	23,630	6.9
Chimney Liners	3,828	1.1
Water Heaters	65,811	19.3

2.2.3 Residential Buildings – Other

The American Housing Survey also provided information on the number of households with kitchen sinks and garbage disposals (about 99 and 44% of the total, respectively). According to the Specialty Steel Association of America, stainless steel sinks were introduced in 1933. The 2004 U.S. Housing Census for Connecticut reports that 76% of housing in the state was built after 1939, and it assumed that only these houses could have stainless steel sinks. The U.S. Department of Commerce reports that about 57% of the kitchen sink market is stainless steel units. These factors are multiplied to estimate the number of stainless steel kitchen sinks in Connecticut. Sink weights are taken from manufacturer specifications. The weight of a typical (0.5–1 hp) garbage disposal was averaged from manufacturer specifications (Anaheim) and the ferrous content was assumed to be 85%.

Concrete septic tanks also make use of iron in the steel reinforcement (a small percentage of septic tanks are made out of steel entirety). The American Housing Survey for the Hartford Metropolitan Area reports that 23% of houses are on septic systems, which was again extrapolated to the entire state. It was assumed that 80% of all septic systems are concrete. The Connecticut Department of Public Health (CT DPH) sets standards for septic systems in the state, the minimum volume being 1,000 gallons. A minimum wall thickness of three inches was assessed from the International Conference of Building Officials. From these numbers, the total volume of concrete in a septic tank was calculated and multiplied by a steel reinforcement factor of 1% to find the volume of steel, and hence the mass.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Residential Buildings – Other	**28,293**	**8.3**
Kitchen Sinks	2,808	0.8
Garbage Disposals	3,048	0.9
Septic Tanks	22,437	6.6

2.2.4 Commercial Structures

The Energy Information Administration (EIA) of the U.S. Department of Energy tracks energy use in commercial buildings through its CBECS inventory. It reports the number of commercial buildings in certain size categories for the New England Census division. These numbers were scaled by population and multiplied by the median of each size category to estimate the total floorspace of commercial buildings in Connecticut. CBECS also tracks the number of buildings by their height, which was used to calculate overall percentages of floor space in one-story buildings, two-story buildings, etc.

Survey data were analyzed to find the proportion of structures with exterior walls of reinforced concrete, masonry, glass and steel, etc. Concrete buildings make up 25% of the total; of this, 90% was assumed to be steel-reinforced. Masonry buildings make up 55.2% of the total and 95% of these were built after 1900. Those 5% of masonry buildings that were built in the 19^{th} century were assumed to be timber-framed and therefore contain no steel in the building envelope. The remaining 19.8% of commercial buildings was assumed to be steel-framed.

The amount of steel per square foot depended on the exterior wall type and was taken from the literature (Seo and Hwang 1999; Guggemos 2003) and from industry consultation (Wang 2006).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Commercial Structures	**5,084,585**	**1,493.0**
Masonry/Brick	1,341,638	394.0
Concrete	1,749,650	513.8
Steel	1,993,297	585.3

2.2.5 Commercial HVAC

The ventilation ductwork and emergency sprinkler systems of commercial (and industrial) buildings are important components of the total steel stock. Iron per square foot factors for these systems were derived from two sources (Wang 2006; Guggemos 2003), averaged, and multiplied by the total commercial floorspace.

The EIA CBECS report includes chapters on the number and type of HVAC equipment used in commercial buildings in the New England Census division. These data were again scaled by population to find estimates for Connecticut. For heating, equipment types included heat pumps, furnaces (assumed to be gas-fired), individual space heaters, boilers (assumed to be oil-fired), and packaged heating units. Buildings were grouped by height (as above) and the number of HVAC units was adjusted as follows: it was assumed that multi-story buildings with gas furnaces have one unit per floor, and that buildings using space heaters are all single-story and have two heating units. The average weights of each unit type were taken from manufacturer specifications (Ingram's Water and Air Equipment; General Electric; Heatershop; Burnham Commercial Cast Iron). Ferrous content for these equipment types were assumed to be the same as for residential heating units, with packaged heating units having a 60% ferrous content.

Cooling unit types included central air conditioners, central chillers, packaged units, and swamp coolers. Portable air conditioners were considered as commercial equipment and so were not included in this category. Heat pumps were disregarded as they function as both heating and cooling units and were accounted for above. Average weights were taken from manufacturer specifications (Dunham-Bush; Thermalcare; Air & Water). As in the residential case, central air conditioning units were assumed to have a ferrous content of 46%. It was assumed that packaged units and swamp coolers are 60% iron, while central chillers are 80% iron.

Refrigeration data covered walk-in coolers, open cases, and closed cases and cabinets. Walk-in coolers are typically lined with aluminum sheeting and insulation, so that the only stock of iron is in the cooling unit itself. These were assumed to be of the central air conditioning type. Average weights of cases and cabinets were taken from manufacturer specifications (Base Equipment; Bigtray), and the ferrous content was assumed to be 60%.

Water heaters were of central, distributed, or combined types. It was assumed in all cases that the buildings used a single commercial-sized water heater weighing 1700 pounds (Hubbell Heaters, online at http://www.hubbellheaters.com) and with a ferrous content of 60% (as in the residential case).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Commercial HVAC	**858,650**	**252.1**
Ventilation and Sprinklers	788,475	231.5
Heat Pumps	269	0.1
Gas-fired Furnaces	6,527	1.9
Oil-fired Boilers	17,438	5.1
Space Heaters	69	0.0
Packaged Heating Units	8,691	2.6
Central Air Conditioning	245	0.1
Central Chillers	982	0.3
Packaged A/C Units	17,163	5.0
Swamp Coolers	108	0.0
Walk-in Freezers	568	0.2
Built-in Refrigerated Cases	1,265	0.4
Water Heaters	16,851	4.9

2.2.6 Commercial Buildings – Other

The number of commercial stainless steel sinks was estimated according to business type. The 2002 U.S. Economic Census provided the number of food service places, hotels, hospitals, and nursing homes. Studies of the tourism industry published the number of hotel rooms in the state, which were averaged (EPA, 2005; Connecticut Center for Economic Analysis, 1999). Each hospital was assumed to have 500 rooms; each nursing home 40 rooms. About 10% of hotel rooms were assumed to have a stainless steel sink, hospital and nursing home rooms were assumed to have one each, and food service establishments were assumed to have four each. For offices, an estimate of one stainless steel sink per 50 employees was used, based on a study published by the Bonneville Power Association. Employee numbers were taken from the Connecticut Department of Labor (CT DOL). Typical weight and ferrous content were taken to be as in the residential case.

The Connecticut Department of Public Safety (CT DPS) Bureau of Elevators has registered 15,000 elevators in the state. An average weight of 681 kg per elevator was derived from manufacturer specifications and newspaper articles (Phipps 2005). It was assumed that elevators have a ferrous content of 95%.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Commercial Buildings Other	**65,350**	**19.2**
Commercial Sinks	55,643	16.3
Elevators	9,707	2.9

2.2.7 Industrial Structures

The total floorspace of manufacturing buildings in the state was found using the EIA's Manufacturing Energy Consumption Survey (MECS), which published the average floorspace per building according to NAICS code. The 2002 U.S. Economic Census for Connecticut provided the number of Connecticut industries by NAICS code. These two factors were multiplied to find the industrial floorspace for different sectors. Industrial buildings have widely ranging functions and therefore steel concentrations per square foot. The use of overhead cranes, conveyors, extensive ventilation, and heavy piping, for example, all increase the steel intensity of industrial buildings. Based on published studies and consultation with architecture and construction firms, the following steel concentrations were adopted (Seo and Wang 1999; Wang 2006; Guggemos 2003):

- 11.3 kg per square foot for food and beverage, textiles, apparel, wood and leather products, paper, printing, furniture, and miscellaneous manufacturing. This concentration was also assumed for industrial office space, which was found to occupy approximately 10% of the industrial floorspace;

- 18.6 kg per square foot for computer, semiconductor, and electrical equipment manufacturing;
- 23.2 kg per square foot for heavy manufacturing – plastics and rubber, primary metals, fabricated metals, machinery, and transportation equipment manufacturing;
- 41.8 kg per square foot for petroleum, chemicals and pharmaceuticals, and nonmetallic minerals.

Power plants and utilities were considered separately. The EIA provided data on the generating capacity of all power stations in Connecticut. Steel requirements for different types of power plants (e.g., nuclear, coal-fired, wind) were found on a per megawatt basis (Peterson 2005). These two data sets were multiplied together to find the total amount of iron residing in power stations in the state.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Industrial Structures	**8,256,005**	**2,424.3**
Manufacturing	7,956,074	2,336.2
Power Plants	299,931	88.1

2.2.8 Industrial HVAC

Ventilation and sprinkler systems were derived as in the commercial case. The EIA's MECS also provided information on the amount of energy consumed by HVAC equipment by industry. Total electricity and gas (but not oil) consumption was found by summing over all industries. It was assumed that all electricity goes to air conditioning units, and all gas to furnaces, and that each is used only 150 days out of the year. The proportion of different air conditioning units (packaged, central, or chiller) was taken to be equal to that of commercial buildings, and the typical electricity consumption per unit for each was found from online sources, the highest being a 40 kW chiller. For furnaces, a gas consumption of 120 cubic feet per hour was assessed (Engineering Toolbox 2006 online at http://www.engineeringtoolbox.com/natural-gas-consumption-d_172.html). Dividing the total consumption by the unit consumption gave the number of units. Typical weights and ferrous contents were taken to be as in commercial buildings. Considering oil-fired boilers, industrial buildings were assumed to have the same proportion of gas furnaces to oil-fired boilers as commercial buildings. This factor was multiplied by the number of gas furnaces, the typical weight of a boiler and a ferrous content of 95% (as in the commercial case) to find the iron stock in industrial boilers.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Industrial HVAC	**390,951**	**114.8**
Ventilation and Sprinklers	363,962	106.9
Heating	17,332	5.1
Cooling	9,657	2.8

2.3 EQUIPMENT

Iron is in many, if not most, domestic and commercial appliances, as well as in industrial machinery. While the amount of iron in any one product (e.g., washing machines) is small compared to that in automobiles as a whole, the sheer number of different products makes this category significant in terms of total stock. This study has attempted to include all products that contain significant amounts of iron. However, there are thousands of others that could be included – each with a small amount of iron – making a truly comprehensive study impossible. For this reason, there may be undercounting in this category.

2.3.1 Domestic "White Goods"

This category includes refrigerators, clothes washers, dryers, dishwashers, stoves and conventional ovens, microwave ovens, and portable air conditioners. Ownership data for all but microwave ovens were collected from the 1996 American Household Survey for Hartford and extrapolated over the whole state. The weight of products was found from moving estimates (Interdean Interconnex), manufacturer specifications, and research studies (Appliance Recycling Information Center (ARIC), online at http://www.aham.org/aric/2aric.pdf). ARIC also provided ferrous iron concentrations for every case, as well as the percentage of households with microwave ovens.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Domestic "White Goods"	**254,423**	**74.7**
Refrigerators/Freezers	58,494	17.2
Washing Machines	43,148	12.7
Clothes Dryers	34,648	10.2
Dishwashers	16,338	4.8
Stoves/Domestic Cooking Ranges	68,350	20.1
Microwave Ovens	14,448	4.2
Portable Air Conditioners	18,997	5.6

2.3.2 Domestic Electrical and Electronic Appliances

The per capita number of computers, televisions, and radios is tracked by the United Nations World Development Indicators reports. It was assumed that Connecticut ownership trends are identical to those reported for the entire country. Typical weights were taken from representative product specifications and the literature (Compaq; Dell; Lee *et al.* 2000). The ferrous content of 19% for computers was published by a study by the German Federal Ministry for Economic Cooperation and Development (Siemers and Vest 1999). Televisions have an even lower ferrous content of 10%, as reported in the literature (Nakamura and Kondo 2001).

The Federal Communication Commission and Nationmaster record the percentage of households with fixed line and mobile phone subscriptions. It was assumed that each household with a fixed telephone connection had an average of 1.5

phones. The average weights of each type of phone were derived from consumer reports (Wireless Guide, online at http://www.wirelessguide.org/phone/choosing-phones.htm). Waste Electronics and Electrical Equipment (WEEE) has an overall ferrous content of 6%. Mobile phones were assumed to fall into this category, while mainline phones were assumed to have a slightly higher iron content of 7%.

The EIA tracks the energy consumption of residential appliances, including home office equipment such as fax machines and copiers, for the New England region. These numbers were scaled by population to estimate the number of units in Connecticut alone. Ferrous contents were derived from environmental product declarations (Ricoh, online at http://www.environdec.com/reg/e_epde4.pdf)

	Iron Stock (Mg)	*Per Capita (kg/c)*
Domestic Electrical and Electronic Appliances	**20,095**	**5.9**
Computers	6,364	1.9
Televisions	8,694	2.6
Telephones	255	0.1
Stereos/Radios	2,606	0.8
Fax Machines	480	0.1
Copiers	864	0.3
Sewing Machines	380	0.1
Irons	451	0.1

2.3.3 Other Domestic Equipment

Iron in kitchens is found primarily in tableware and pots and pans. Approximately 70% of the tableware market in the United States is stainless steel (Moran 2001). Factor Multipliers of eight eating utensils per person, five serving utensils per household, and seven cooking utensils (including knives) per household were assumed. Stainless is again assumed to have 74% iron content. Considering pots and pans, each household was assumed to own eight pots and pans of various sizes. About 43% of the domestic market for pots and pans is stainless steel, while 3% is cast iron (Blumenthal 1992; Moran 2005). Weights for both utensils and pots and pans were found in online catalogs.

Many types of food containers are so-called "tin cans." In reality, these are only thinly plated with tin and contain 99.7% steel. According to the Spokane Regional Solid Waste System, the average person uses 142 cans annually, and the average can weighs 2.5 ounces. Unlike the other products considered here, cans are constantly moving through residences as food is consumed and the cans are discarded. Using a one-month residence time gives a per capita stock of 0.84 kg iron in cans at any one time.

According to Mediamark Research, 33% of U.S. households own sewing machines, while 49.5% own irons. Typical product weights were found from online catalogs. Sewing machines were found to have 15% ferrous content (VSM, online at http://www.environdec.com/reg/epde27e.pdf). Irons were assumed to have a ferrous content of 50%.

Approximately 60% of the weight of mattresses and box springs is in the steel coils (G.I.E. Media 2001). It was assumed that each person in Connecticut owns one queen-sized bed.

Steel filing cabinets are used in many households; it was assumed that each housing unit contains one. A ferrous content of 95% was assumed, while a typical weight was derived from representative product specifications (Hon filing cabinets, online at www.hon.com).

Iron is found in basements and garages in the form of tools and yard equipment (represented here by lawn mowers and snowblowers). Eighty percent of households were assumed to have a toolbox of some kind with an average weight of 40 pounds. Most tools contain steel, and so an overall ferrous content of 85% was assumed. The total number of lawn mowers in use in the country was found from a consumer group (Consumer Reports 2005 online at http://www.greenerchoices.org/products.cfm?product=lawnmower&page=WhyItMatters) and scaled by population to Connecticut. The average weight of a lawn mower was assumed to be 30 kg, which incorporates both push-mowers and riding mowers. Approximately 15% of households own a snowblower (Mediamark Research 2000). The average weight was derived from manufacturer specifications (Honda; Toro). It was assumed that both lawnmowers and snowblowers are composed of 80% iron.

Mediamark Research also reports that 22.7% of American households own a grill. Typical grill weights were averaged from manufacturer specifications and a ferrous content of 85% was assumed.

The Washington Post reports that 16.7% of adults in Connecticut own guns (online at http://www.washingtonpost.com/wp-srv/health/interactives/guns/ownership.html). This was multiplied by the over-18 population of the state, as reported by the 2000 U.S. Census. The typical type and number of guns per owner was derived from data reported by the U.S. Department of Justice. Average weights of various gun types were taken from online articles (Hawks 2003; Gun Directory, online at http://www.gundirectory.com). A general ferrous content of 83% was assessed from trade articles (Metcalf 2000).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Domestic Other	**114,762**	**33.7**
Tableware	2,403	0.7
Steel/tin Cans	2,849	0.8
Pots and Pans	5,318	1.6
Charcoal/Gas Grills	5,696	1.7
Beds	38,927	11.4
Filing Cabinets	26,082	7.7
Tools	16,060	4.7
Lawn Mowers	10,165	3.0
Snowblowers	3,543	1.0
Guns	3,718	1.1

2.3.4 Commercial "White Goods"

This category encompasses the same product types as the residential case, but the locations of commercial white goods are much more diverse. They are found in educational institutions, hotels, offices, retail stores, restaurants, laundromats, and many other commercial establishments. In all cases, the ferrous contents were taken to be identical to those given in the residential white goods category.

In order to find the number of refrigerators/freezers in educational institutions, an inventory at Yale University cafeterias was conducted. These numbers were adjusted for the enrolled student population in Connecticut to find the total number owned by universities. The National Center for Education Statistics reports the number of primary and secondary schools in the state. It was assumed that each school cafeteria contains three refrigerators/freezers. It was assumed that 25% of students have a small refrigerator in their dormitories. This was multiplied by the on-campus student population to find the total number of student-owned refrigerators.

The average number of refrigerators per hotel room was taken from a survey conducted for the City of New Haven (Rostkowski *et al.* 2007). The number of hotel rooms in the state was taken from a variety of sources and averaged (EPA Energy and Environmental Analysis 2005; Connecticut Center for Economic Analysis 1999; Cartenson *et al.* 2001; http://www.hotel-online.com/News/PR2005_4th/Oct05_HartfordProvidence.html). The CT DOL reported the total number of employees in Trade, Finance, Real Estate, Insurance, Services, and Government sectors. Based on guidance from the Bonneville Power Administration, a factor of one refrigerator per 50 employees was assumed. The 2002 Economic Census reports the number of food and beverage stores in Connecticut. It was assumed that each of these owned one full freezer and five refrigerated cases. The Census also reports the number of eating and drinking establishments in the state, and it was assumed that each owned two refrigerators. The total number of refrigerator/freezer units was tallied by size category. Typical weights for each category were derived from manufacturer specifications (Haier America; Norlake Refrigeration; Vending 101).

Washing machines and dryers at educational institutions and hotels were calculated as above. The U.S. Economic Census reports the number of laundromats in the state; it was assumed that each facility owned 15 washers and dryers each. Typical product weights were taken from manufacturer specifications (Edrodynawash; Roper).

The number of commercial dishwashers, stoves, ovens, steamers, and deep fryers was found for educational institutions and eating and drinking establishments, as for refrigerators/freezers. It was assumed that each establishment owned one large dishwasher, two large stoves, and that 20% of institutions owned a deep fryer. Average weights were derived from the Yale University survey inventory, online sources (http://www.canbake.com/products.html), and manufacturer data (Henry Penn Corporation). Fryers were assumed to contain only stainless steel.

Estimates for microwave ovens were made from hotels, various economic sectors, and eating and drinking establishments, as for refrigerators/freezers. It was assumed that 15% of students in dormitories own a microwave oven, that there is one oven per

50 employees in the above sectors, and that each eating and drinking establishment owns one microwave oven. Commercial unit weights were averaged from trade articles.

Ice machine estimates were made for educational institutions as above. The 2002 Economic Census reported the number of groceries, convenience stores, and beer, wine, and liquor stores. It was assumed that each of these stores owned one machine and that they are completely stainless steel.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Commercial "White Goods"	**71,109**	**20.9**
Refrigerators/Freezers	5,553	1.6
Washing Machines	824	0.2
Clothes Dryers	951	0.3
Dishwashers	558	0.2
Stoves/Ovens/Steamers	2,749	0.8
Microwave Ovens	471	0.1
Portable Air Conditioners	59,369	17.4
Fryers	392	0.1
Ice Machines	243	0.1

2.3.5 Commercial Electric and Electronic Appliances

The Northeast Product Stewardship Council reported the number of computers used per employee for various economic sectors. These factors were multiplied by the number of employees in each sectors (as reported by CT DOL) to find the total number of computers in commercial institutions. The Connecticut Department of Education published the number of computers per student for elementary and secondary schools in the state, as well as the total number of students enrolled. The number of computers at post-secondary educational institutions was scaled by student population from the Yale University inventory. Weights and ferrous content were assumed to be identical to the residential computers case, above.

Televisions in hotels, educational institutions, and offices in various economic sectors were counted as in the case of refrigerators. It was assumed that these offices contained one television per 50 employees. It was also assumed that 25% of students in dormitories own a television. The Connecticut Hospital Association reported the number of hospital beds in the state, and it was assumed that there is a television for each bed. Drinking establishments in Connecticut are assumed to have 1.5 televisions on average. Weights and ferrous content were assumed to be identical to the residential televisions case, above.

Telephone numbers were estimated in educational institutions and hotels, as above. It was assumed that in offices, the number of telephones and computers were equal. The average weight of an office telephone was assumed to be 2 kg, slightly higher than the residential case. The ferrous contents were assumed to be identical, or 7%.

Stereos were counted from offices and eating and drinking establishments, as above. It was assumed that there is one stereo for every 100 employees in offices and that 50% of students in dormitories own a stereo. The average weight of a stereo was averaged from online catalogs and the ferrous content was assumed to be 10%.

The number of portable air conditioners was assumed to be equal to the number of hotel rooms in the state. Average weight and ferrous content was taken to be identical to the residential case.

The number of photocopier units per million square feet was reported by the EIA. This is multiplied by the commercial building square footage derived for the Buildings category to arrive at a total number of units. The EIA also reported a factor for the number of copiers per commercial office employee (Ruth *et al.* 2002). These totals were averaged and multiplied by 110.3 kg of iron per copier, as reported by Ricoh in an environmental product declaration (online at http://www.environdec.com/reg/e_epde4.pdf).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Commercial Electrical and Electronic Equipment	**13,771**	**4.0**
Computers	5,527	1.6
Televisions	224	0.1
Telephones	195	0.1
Stereos/Radios	37	0.0
Copiers	7,787	2.3

2.3.6 Other Commercial Equipment

Beds found in hotel rooms and hospitals were accounted for, both in the mattresses and the frames. It was assumed that each hotel room contains one twin bed and that all frames are metal.

Most commercial offices contain filing cabinets. Per employee factors were assumed for each economic sector and then multiplied by the number of employees. Typical weight and ferrous content were as above in residential equipment. Considering desks/tables and office chairs, it was assumed that their numbers are equal to those of filing cabinets. It is usually the table or desk legs that are made of steel and these were assumed to weigh 20 pounds per unit. A typical ferrous content of an office chair was found in an environmental product declaration for Steelcase (online at http://www.steelcase.com/files/dyn/3efc64a6dce742e6bbf8e818ef676326/04-0012421.pdf).

Retail establishments are the largest category of economic sectors in Connecticut and contain a large stock of steel in shelving. Typical shelf weights were found from manufacturer specifications (Hong Da, Jesse Heap). The number of establishments of each retail sector was found from the 2002 Economic Census while the average floor spaces were calculated from CBECS data. Based on field investigation, it was assumed that, for non-apparel stores, 70% of the store contained shelving and that aisles were spaced at 12 feet. For apparel stores, it was assumed that there exists one clothes rack per 20 square feet, again assuming 70% of the floor space is for the showroom.

The 2002 Economic Census reports the number of full-service restaurants and automotive repair shops in Connecticut. Nickel magazine published an estimate of the amount of stainless steel that goes into a new McDonald's in China; it was assumed that this amount is the same as for all restaurants. Based on weight inventories of auto-body shops (online at http://www.toolsusa.com/AutoBodyTools), it was assumed that each shop contained 1000 pounds of tools, with an average ferrous content of 85%.

Considering shopping carts, the 2002 Economic Census reports the number of retail establishments in the state (excluding furniture stores, which do not commonly make use of shopping carts). Based on field investigation, it is assumed that about half of these stores are large enough to warrant the use of shopping carts and that, on average, each store has a stock of 200 shopping carts. It was also found that approximately 80% of shopping carts weigh about 20 kg and are about 70% iron.

Tosca Limited reports the number of beer kegs sold in U.S., which was scaled to the population of Connecticut. It was assumed that kegs have a residence time of one week, and like steel cans they are temporary stocks of iron. Kegs were assumed to be 100% stainless steel.

Tableware estimates were made as in the residential case, based on the number of eating and drinking establishments in the state.

Most commercial businesses make use of steel dumpsters to store waste. The weight of a typical dumpster was found to be 700 lbs. The number of commercial and industrial buildings was derived as above and it was assumed that each commercial building makes use of two dumpsters and that each industrial building makes use of six.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Other Commercial Equipment	**542,483**	**159.3**
Beds	1,302	0.4
Filing Cabinets	15,484	4.5
Shelving	431,619	149.9
Desks/Tables	7,400	2.2
Office Chairs	5,812	1.7
Restaurant Cooking Equipment	6,992	2.1
Tableware	97	0.0
Automotive Tools	807	0.2
Shopping Carts	14,501	4.3
Kegs	37	0.0
Laboratory Equipment	17,249	5.1
Dumpsters	41,183	12.1

2.3.7 Agriculture and Forestry

The National Agricultural Statistics Service provides farm acreage on the farming sector in Connecticut. Informal estimates suggest that a typical farm owns one tractor and three large pieces of machinery, such as balers or front loaders. Machine weights were averaged from manufacturer specifications (Buhler Industries; John Deere) and an 85% ferrous content was assumed. Based on field investigation, it was assumed that each licensed logger in the state uses a harvester and a forwarder. Machine weights were taken from manufacturer specifications and were multiplied by the number of licensed loggers in the state, as reported by Mount Wachusett Community College (online at http://www.mwcc.mass.edu/programs/FWP/logger.html).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Agriculture and Forestry	25,456	7.5

2.3.8 Transportation and Warehousing

The warehousing sector was reported to use one forklift per eight employees (DHL, online at http://www.us.danzas.com/offices/office_detail.cgi?office_id=68). Based on labor statistics, it was estimated that this factor is one forklift per 50 employees in the manufacturing sector. Typical weights were derived from online auctions and a 70% ferrous content was assumed. The warehousing sector also makes use of extensive steel shelving. The typical size of a warehousing operation was calculated from CBECS microdata. It was assumed that 90% of the total floorspace is dedicated to storage. Units are 24 feet high, four feet deep, and have a 20 foot aisle spacing. Shelving weights were taken from manufacturer specifications (Edsal).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Transportation and Warehousing	16,869	5.0
Forklifts	16,869	5.0
Shelving	40,598	11.9

2.3.9 Manufacturing Equipment

The iron present in small manufacturing machinery was the most difficult category to estimate with confidence. Two methods were employed: using machine-to-employee ratios and using published data for one manufacturing sub sector and then extrapolating to the others. Site visits and industry contacts provided data on the number of industrial machines per employee for several manufacturing sub sectors. Typical weights of metalworking machines were averaged from manufacturer specifications (Grizzly; Keko Equipment) and an iron concentration of 81.2% was established (Personal Communication, Terry Smith, Dixie Corporation; Progressive Technologies). The percentage of computer numerically-controlled (NC) machines used in metal fabrication was found (NMTBA, 1992) and the larger masses of these machines incorporated into the calculation. For other manufacturing sectors, the average weight of typical machinery for that sector was used. The second method used data from the 14^{th} American Machinist Inventory to find the number of metal cutting, forming, joining, and assembly machines in Connecticut (NMTBA, 1992). The inventory covered several manufacturing sub sectors (specifically SIC codes: 25, 33, 34, 35, 36, 37, 38, 39), including metal fabrication and machinery. These sectors comprise the large majority of manufacturing firms in the state of Connecticut. The number of machines per employee based on this inventory was extrapolated to the remaining manufacturing sub sectors. These two estimates were averaged to arrive at the final iron stock in small manufacturing machinery.

Apart from small machines, manufacturing facilities also make use of large machines that are built into the facility but not considered in the buildings calculations above. These can be water treatment plants, electroplating systems, or large process machines, among others. Based on facility visits, it was assumed that each industrial facility in Connecticut has four of these large machines. A typical weight for these machines was derived from manufacturer specifications (Horizon) and the regular ferrous content of 82.1% was applied.

Large shelving units in manufacturing facilities were considered using the same factors as for warehousing facilities. It was assumed that 3% of the total floorspace is dedicated to shelving and storage.

The Connecticut Department of Public Safety, Office of the State Building Inspector contains a Bureau of Boilers that is responsible for registering and inspecting all of the boiler units in commercial and industrial buildings in the state. They report that there are approximately 40,000 boilers in use currently (personal communication, 2006). The number of boilers used for heating was subtracted from this number to estimate the quantity of process boilers.

Many industries still make use of steel 55-gallon drums; it was assumed that each manufacturing facility in the state has a standing stock of 20 drums. The tare weight of a drum was found to be 45 pounds (Gurman Container Supply) and a ferrous content of 98% was used.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Manufacturing Equipment	**494,813**	**145.3**
Small	230,056	67.6
Large	186,063	54.6
Process Boilers	19,219	5.6
Shelving	57,322	16.8
Steel Drums	2,154	0.6

2.3.10 Construction

Unlike large and specialty trucks that travel on roads and therefore require state license plates and registrations, much heavy construction equipment is brought to worksites on flatbed trucks. The only place that the equipment might be registered is on the local tax assessor rolls for personal property, which are often incomplete and difficult to aggregate. The Department of Environmental Protection, however, records the sale of construction machinery to in-state firms in order to track air emissions from diesel engines (CT DEP 2006). The records cover dozers, loaders, excavators, graders, and articulated trucks over a period of ten years. The lifetimes of each of these machine types was found from trade magazine articles (Stewart 2004), allowing for an estimate of the number of machines at any one time. Typical weights were found from manufacturer specifications (Komatsu America; Kawasaki). A ferrous content of 90% was assumed for these vehicles.

Although they are not significant in number in Connecticut, construction cranes concentrate so much iron that they constitute an important stock. It was assumed that six large cranes are in use at any one time, approximately one for each major city in the state. Large cranes were found to weigh about 300 tons each. Medium-sized cranes were inventoried from the major ports and smaller construction projects and were assumed to weigh 100 tons each. Nowadays, crane counterweights are often concrete, but the structure is almost entirely steel (personal communication, William Dalrymple, Editor of Cranes Today, 2006). Therefore, it was assumed that cranes have a ferrous content of 85%.

Hand tools were also considered. The 2002 Economic Census published the number of construction workers in the state. It was assumed that each worker has a tool set weighing 50 pounds and that the tools are 90% iron.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Construction	**62,111**	**18.2**
Vehicles	56,030	16.5
Cranes	5,089	1.5
Tools	991	0.3

2.4 INFRASTRUCTURE

Infrastructure is the last major category of iron stocks. The system with the most iron is that of water distribution, which utilizes iron and steel pipes almost exclusively for its mains. A significant amount of iron is also found in the storm sewer system as well as in steel-framed bridges.

2.4.1 Water Distribution

The Connecticut Department of Public Utility Control (CT DPUC) requires an annual report of all Class A water companies in the state, which includes sections on the length and material type of the pipes in its water supply and distribution systems. These data were collected for all reporting water companies, the largest of which is Aquarion, Inc. of Danbury. Using the length of different sizes and types of pipe, as well as standard pipe thicknesses from ASTM/AWWA standards, a total volume of each type of material (cast iron, ductile iron, steel, etc.) was calculated. This was multiplied by the density of the material and the iron content to reach the total mass of iron in the water pipes. Service connection pipes were also treated in this manner.

Data were also collected on the number of fire hydrants and pumps. Hydrants were assumed to be pure iron, while pumps were assumed to be stainless steel. These numbers were multiplied by the average weight of hydrants and pumps (400 pounds and two tons, respectively) and by the percent iron content to find the mass of iron in these items.

Not all houses, however, are served by water companies; a significant number use private wells for their water source. The Connecticut Department of Environmental Protection (CT DEP) prepared a report for the state Legislature stating reports that the number of private wells in use in the state is approximately 250,000. The National Agricultural Statistics Service estimates the average depth of a well in Connecticut to be 138 feet. It was assumed that the only iron in a well is the steel well casing and that this has a diameter of six inches.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Water Distribution	**1,659,158**	**487.2**
Supply and Distribution Mains	1,273,428	373.9
Hydrants	9,780	2.9
Service Connections	64,155	18.8
Pumps	943	0.3
Private Wells	310,853	91.3

2.4.2 Natural Gas Distribution

The National Office of Pipeline Safety (OPS) collects information on all natural gas pipelines in the United States, including the length and material type of each company's distribution system. There are four gas companies in Connecticut that maintain gas pipeline infrastructure. As with the water distribution system, data about these networks were collected, summed, and multiplied by the pipe thickness and material density to find the total mass of iron in the system. Most of the pipes are of cast iron or steel. The majority of service connections are built with steel pipe with a diameter between 0.75 and 1.5 inches. Data on the average length of service connections were also available for each company, which were used to compute the total volume of metal and hence the total mass of iron.

Meters were also considered, though they contribute a small mass relative to the mains. According to the 1996 American Housing Survey conducted for Hartford, 26.4% of households use gas for cooking and 39.7% use gas for water heating. Assuming the gas usage in Hartford is representative of the state, it was found that approximately 520,000 households in Connecticut use natural gas (and therefore have meters). Using the total number of service connections from the OPS data, this gives an average of 2.7 meters per service connection, a not unreasonable number. An average residential meter weight of 13 pounds was assessed using commercial product specifications (Invensys).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Gas Distribution	**294,219**	**86.4**
Mains	282,556	83.0
Service Connections	8,578	2.5
Meters	3,085	0.9

2.4.3 Oil Storage and Distribution

Connecticut is a regional hub for oil storage, and supplies much of southern New England via a pipeline. Oil tanks are concrete-lined steel and their sheer size makes them an important category for this study. New Haven Harbor receives 80% of the oil tankers that supply Connecticut. Drakonakis *et al.* (2007) detailed the iron present in each tank in New Haven based on aerial photographs. This work was expanded to include the other deepwater ports of New London and Bridgeport. Measurements were taken using satellite images from Google Earth®. An average tank height of 50 feet was assumed, as well as an average steel wall thickness of 2.5 inches. As above, the total volume of steel was multiplied by its density to give the mass of iron in oil storage tanks. It was further assumed that each tank has attendant pumping and processing equipment with a mass equal to 40% of that of the tank.

The oil pipeline is owned by Buckeye, Inc. and runs 112 miles from New Haven, via Hartford and Bradley airport, to Springfield, Massachusetts. Based on data from other pipelines owned by the company, it was assumed that the pipeline was 12 inch diameter steel. A standard pipe thickness of 0.37 inches was assumed.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Oil Storage and Distribution	**113,213**	**33.2**
Tanks	100,494	29.5
Pipeline	12,719	3.7

2.4.4 Storm Sewers

Iron is an important redox chemical in nature, and for this reason, it is generally not used in sewer systems where it would react with organic matter and corrode. In accordance with USEPA and CT DEP regulations, most of the historically combined sewer systems in the country have been separated, so that during periods of heavy rainfall, untreated sewage is not released into the streets or into rivers via combined sewer overflows. This leaves a separate storm sewer network, the great majority of which uses reinforced concrete pipes. Following Drakonakis, *et al.* 2007, the cross-sectional area of rebar in these concrete pieces is assumed to be equal to the amount found in the four inch cast iron pipe. The USEPA has promulgated a series of regulations mandating the installation of storm sewer drains for communities of a certain minimum population. Using demographic maps of Connecticut was possible to find the areas where storm sewers have been mandated, with the resulting estimate that 50% of roads in the state have storm sewers. The CT DOT gives the total length of roads in the state as 20,844 miles. Multiplying this distance by the percentage road coverage of the storm sewer system and the pipe diameter, thickness, and density (as above) gives the total iron stock.

Manhole covers and storm grates are also important components of the storm sewer system. Standards for highway construction promulgated by the Connecticut Department of Highway Engineering mandate that the minimum spacing of manholes and storm grates in highways to be 300 feet. This gives a factor of 17.6 manhole covers or storm grates per mile. On local roads, field investigation revealed the factor to be closer to 22 storm grates per mile. These factors were multiplied by the length of highways and local roads in the state and the assumed weight of a manhole cover (100 pounds) and a grate (50 pounds) to reach the total mass of iron in manhole covers and grates.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Storm Sewers	**319,880**	**93.9**
Mains	309,219	90.8
Manhole Covers	7,757	2.3
Grates	2,904	0.9

2.4.5 Streetscape

While the standard "Stop" and "Speed Limit" signs are made out of aluminum, the posts that support them are largely steel. Nucor Steel, a commercial manufacturer of signposts, specifies a weight of three pounds per foot for these signposts. Based on an average height of each sign and the weight of the steel footing, a factor of 35 pounds per signpost was calculated. Field investigation in several locations in the state revealed an average of 23 signposts per mile of local road. These factors were multiplied by the 19,433 miles of local roads in Connecticut to give the mass of local road signs. Due to their larger size, highway signposts were assumed to have an average weight of 50 pounds, though in reality some are much lighter and some are much heavier. A study by the CT DOT reported the weight of an overhead truss for highway signs to be 6740 pounds. Field investigation on several parts of the interstate system revealed an average of 34 highway signposts per mile and five overhead trusses per mile. Again, these factors were multiplied by the 1,411 miles of highways in the state to give the mass of iron in highway road signs and overhead trusses.

According to standards promulgated by the CT DOT, the standard height of overhead traffic light supports is 24 feet from ground level. Field observation revealed that most traffic lights are suspended from a cable strung between two supports. For cases where the light is hung from a horizontal steel arm, this arm was considered to be equal to the size of a support pole. It was assumed that half of all intersections with traffic lights also have a shorter auxiliary light, measured at ten feet. The average diameters of the lights were found to be ten inches for overhead support poles and five inches for auxiliary lights. Assuming one traffic light per mile for all roads except interstates, these factors were multiplied by the density of steel to calculate a mass of iron in traffic lights.

United Illuminating and Connecticut Light and Power supply 94% of the electricity market in Connecticut. Based on company reports, the total number of utility poles was found to be 237,000 of which 30% were assumed to have a steel streetlight attached. These "Cobra head" lights have an eight foot arm and are four inches in diameter, with a 0.2 inch thickness. Again multiplying by the density of steel gave the mass of iron in the street lighting system.

Chain-link fencing lines many highways and commercial properties and is common in residential areas. Only a small percentage of commercial and residential chain-link fencing is on road frontage; the total length (including non-frontage fencing) was assumed to be equal to 7% of the total road distance, or about 1,460 miles of fencing. Chain-link fence design does not vary much, and so standards from the City of Lincoln, Nebraska were considered valid to calculate the height, spacing, and therefore the weight of different fencing components (online at http://www.ci.lincoln.ne.us/City/pworks/engine/dconst/standard/stndspec/pdf/chap9.pdf).

Guardrail is another important iron-bearing component of the highway system. A special-interest website (Guard Rails, online at http://www.guardrails.com) provided specifications on the weight per foot of W-type guardrail, which is prevalent, as well as the average spacing and weight of the steel supports. It was assumed that the 346 miles of interstate are lined with four lengths of guardrail and that non-interstate guardrail and sections of the interstate without guardrail balance each other.

Though there are not many billboards in Connecticut, their sheer size makes them a significant stock of iron. The non-profit organization Scenic America states that there are 988 resident billboards. Industry contacts provided physical specifications: billboard frames were found to weigh about 22,000 pounds, while a typical steel support pole was found to be 42 inches in diameter and an average of 50 feet high, with a thickness of 5/8 of an inch.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Streetscape	**145,348**	**42.7**
Signs	30,370	8.9
Traffic Lights	10,754	3.2
Street Lights	7,350	2.2
Chain Link Fence	24,318	7.1
Guard Rail	56,416	16.6
Billboards	16,141	4.7

2.4.6 Rail

The rail system is perhaps the most visible piece of iron infrastructure, though its importance has been declining steadily over the years in the U.S. as a whole. The Association of American Railroads reports that Connecticut has 543 miles of freight corridor and 122 miles of passenger corridor. In addition, a map from the CT DOT showed 157.2 miles of unused freight corridor. It was assumed that freight corridor contained one track, while passenger corridor was split evenly between two tracks and four tracks. Given two rails per track, this gives 2,372 miles of track in the state. Sidings and rail yards were not considered. CT Rail reports a weight of 26 kg per linear foot of rail, which was used to calculate the iron mass.

Much of the passenger corridor length has been electrified, supported by an overhead electrical contact system. Exceptions include the line north from New Haven to Hartford and Springfield, Massachusetts, as well as the Waterbury branch of the Metro North Railroad, giving a total length of electrified track of 142.5 miles. Field investigations revealed a factor of 70 overhead poles per mile, with an average height of 50 feet, a span of 30 feet, and a weight of 48 kg per linear foot. These factors were multiplied to give the iron mass in the system.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Rail	**356,975**	**104.8**
Track	325,683	95.6
Overhead Contact System	31,292	9.2

2.4.7 Roads and Bridges

The National Bridge Inventory tracks the number and size of all bridges in the country, according to the road type and function. In-use and obsolete bridge areas were added from both rural and urban areas. Bridges on minor collector and local roads were considered to be "minor" while all others were considered to be "major". Based on previous studies (Drakonakis *et al.* 2007), minor bridges were assumed to have 20 pounds of steel per square foot of deck area, while major bridges were assumed to have 50 pounds per square foot.

Some roads are constructed using reinforced concrete, particularly those over bridges. The Federal Highway Administration specifies that the steel in reinforced concrete for highways is 0.6% by cross-sectional area. Concrete highway construction uses the jointed reinforced concrete paving (JRCP) design, which has slightly less steel than normal reinforced concrete paving. Therefore the steel concentration was assumed to be 0.5% by cross-sectional area. It was further assumed that 5% of highways in the state used concrete construction. The Federal Highway Administration mandates that the thickness of a highway slab be 230 mm and the minimum lane width be 12 feet. Assuming three lanes for highway roads, the total volume of concrete highway slab was found and then multiplied by the steel concentration and density to find the iron mass.

	Iron Stock (Mg)	*Per Capita (kg/c)*
Roads and Bridges	**882,324**	**259.1**
Reinforced Concrete Roads	13,488	4.0
Bridges	868,836	255.1

2.4.8 Electricity Transmission and Distribution

From self-reporting and industry profiles, data were collected on the transmission and distribution systems of United Illuminating and Connecticut Light and Power (CT DPUC; Electric Power Research Institute, online at http://www.epri.com). It was found that there are about 6 miles of overhead 345 kV line, 1,700 miles of overhead 115 kV line, and 26,300 miles of distribution line. While these conducting lines are aluminum or copper, they are sheathed in steel for support. The steel content of each type of line was found from the Japan Environmental Management Association for Industry (JEMAI, 2003).

The two companies have a stock of about 520 transmission transformers and 325,000 distribution transformers. The weight and iron content of each transformer type was found in environmental product declarations by ABB, a large industrial group (online at http://www.abb.com). 90% of transformers were assumed to be pole-mounted, as opposed to pad-mounted.

Most of the iron in the electricity transmission system is found in the support towers. An exercise from the University of Denver reports 40 poles per mile of overhead transmission line. Each pole was found to be approximately 5000 kg (JEMAI, 2003).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Electricity Transmission and Distribution	**515,058**	**151.2**
Cable	7,719	2.3
Towers	379,522	111.4
Transformers	127,816	37.5

2.4.9 Telecommunications

Trunk or feeder cable in Connecticut is generally fiber optic, but the drop cable that connects to the house is still coaxial cable. The CT DPUC collects data on the total number of customers served by cable companies in the state, about 1.1 million households. The average length of a dropline was found to be 100 feet. It was assumed that all dropline is RG-59 type coaxial cable, which has an inner conducting wire made of steel of standard diameter.

It was assumed that in places where the electricity is carried by overhead wire, the cable would be strung up on poles as well, and similarly for buried cable. Extrapolating the ratio of overhead to buried cable from United Illuminating data, it was found that about 24% of the trunk or feeder cable in the state is buried. It was assumed that there are ten telecom manholes per mile, and that each cover weighs 100 pounds.

As with electricity transmission and distribution, most of the iron in the telecommunications system is in towers. The Connecticut Siting Council maintains a database of all antennas in the state, along with their function, owner, and base height and type. The data were sorted to find the total height of monopoles and lattice towers. Manufacturer specifications were used to determine the average size of the monopoles and lattice guyes and poles (Valmont).

	Iron Stock (Mg)	*Per Capita (kg/c)*
Telecommunications	**129,920**	**38.1**
Cable	52	0.0
Manholes	2,961	0.9
Towers	126,907	37.3

2.5 ERROR

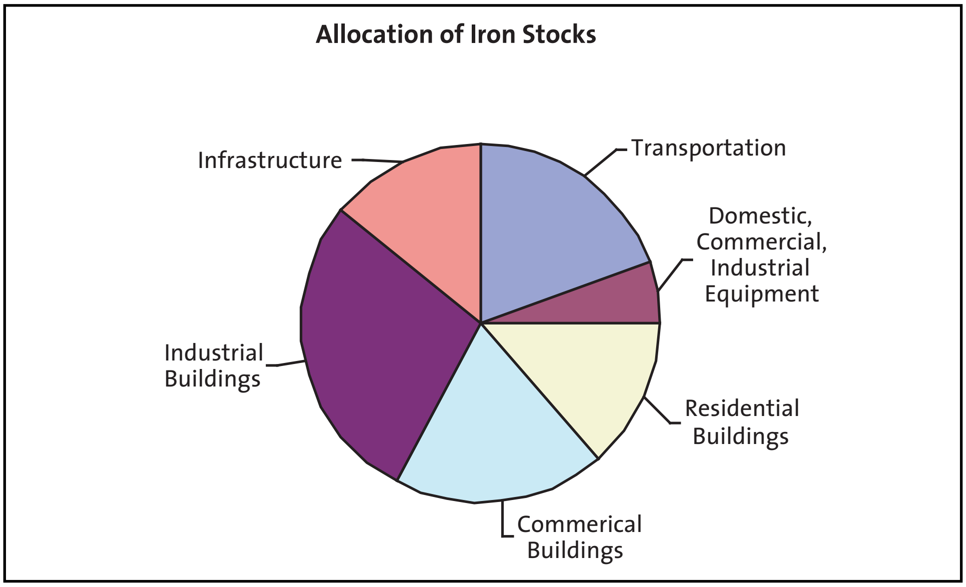
There is uncertainty associated with each category of in-use stocks. Given the wide range of official and unofficial sources used for this analysis and the fact that most did not provide uncertainty estimates, any rigorous statistical treatment would be based on assumptions for standard deviations and therefore somewhat meaningless. There have been calculations of uncertainty for inventories of metal stocks (Lohm *et al.* 1997), but these, too, are based on a range of data points. Therefore, a more qualitative approach to error was adopted. Each category of in-use stocks has associated errors that are rated low (0-10%), medium (10-20%) and high (>20%). These ratings are based on data quality and coverage, the use of informed estimates, and the number of calculation steps.

In addition, a sensitivity analysis was performed to identify the most influential input parameters to the stocks calculation on a total mass basis. A perturbation of 10% was introduced into each input parameter in question and the resulting change in the mass for that category was recorded. These perturbation masses were then divided by the total iron stock to find the percentage change in the overall calculation due to a 10% perturbation in a single input parameter.

3. COMPREHENSIVE RESULTS AND DISCUSSION

Connecticut contains approximately 31,600 Gg (thousand metric tons) of iron in use by humans, or 9,300 kg for every person in the state. Buildings make up the largest category with 59% of the total, with industrial buildings being the largest sub-category. The remaining iron is split among transportation (21%), infrastructure (14%), and equipment (6%).

Figure 1 Relative iron stocks of major product categories



This result is lower than those found in top-down studies (see Figure 2) but only slightly above the earlier result of 9200 kg/c for the City of New Haven (Drakonakis *et al.* 2007). The proximity of these bottom-up results is largely coincidental; in most product categories there is a major difference between the two studies. It is worth examining these differences in detail as they reveal some of the difficulties in performing analyses over different spatial scales.

Per capita stocks of apartment buildings for New Haven are larger than those for Connecticut, as the city has a downtown core with a number of tall commercial buildings and so is not representative of rural areas in the state. New Haven's role as the principal port for oil supplies means that its shipping and oil storage and distribution infrastructure is far in excess of the state average. In addition to these geographically-based differences, more detailed data and refined calculations have substantially lowered the state per capita iron stock in heating systems, ships, gas distribution, and streetscape as compared to the New Haven study. Finally, the category of steel scrap, which is quite significant in New Haven because of regular shipments of scrap from the port, was omitted from the present study, as it is not considered to be "in use."

These decreases in iron stocks were more than offset by significant increases of the per capita stocks in light trucks, commercial and industrial buildings and machinery, and electrical transmission towers. Many new categories were added for the present study. The largest categories of iron stocks in Connecticut are shown in Table 1.

Table 1 Major Categories of Iron Stock in Connecticut

Iron Stock Category	*Per Capita Stock (kg/c)*
Manufacturing Buildings	2336
Commercial Buildings	1493
Residential Buildings	1109
Light Trucks	677
Cars	618
Water Supply and Distribution	487
Marine Transportation	311
Roads and Bridges	259
Commercial HVAC	252
Specialty and Large Trucks	206
Manufacturing Machinery	145
Electricity Transmission and Distribution	141
Commercial Shelving	127
Industrial HVAC	115
Household Equipment	114
Trailers	109
Rail Infrastructure	105

A complete list of categories and the total and per capita in-use stocks in each is included in the appendix, along with their associated error ratings.

Sensitivity analysis revealed the input parameters with the greatest influence on the total stock on a mass basis. Table 2 shows the results of a 10% perturbation on various input parameters.

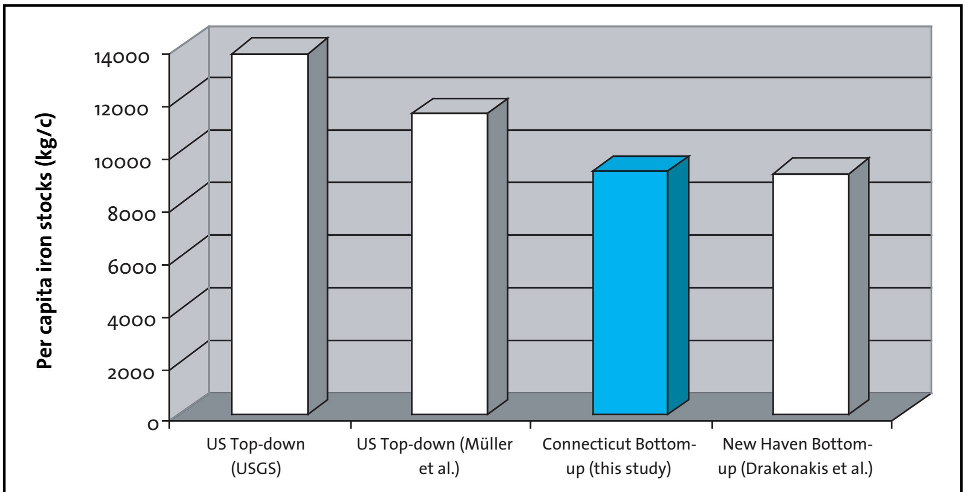
Of these influential input parameters, the steel concentration of various building types carries the most uncertainty and therefore deserves the most scrutiny in future calculations.

One of the major motivations for this study was the potential to examine the methodologies and results of the top-down and bottom-up approaches. Top-down analysis relies on trade data for imports and exports and therefore is only possible to perform on a national scale. As such, a true comparison could only be made with a national bottom-up study. However, we expected that Connecticut would serve as an accurate microcosm of the United States in terms of per capita iron stocks. A comparison of results from various studies is shown in Figure 2.

Table 2 Top twenty input parameters ranked by overall sensitivity using a 10% perturbation

Category	Perturbation (in Gg)	% of Total
Metal Manufacturing Buildings Iron Concentration	395	1.2%
Steel-Framed Buildings Iron Concentration	383	1.2%
Light Trucks Iron Concentration, Weight, # Registrations	231	0.7%
Steel Reinforced Concrete Buildings Iron Concentration	212	0.7%
Cars Iron Concentration, Weight, # Registrations	210	0.7%
Residential Buildings Iron Concentration	173	0.5%
Masonry Buildings Iron Concentration	133	0.4%
Chemicals Manufacturing Buildings Iron Concentration	124	0.4%
Length of Cast Iron Water Mains	109	0.3%
Reinforced Concrete Buildings Iron Concentration	109	0.3%
Electronics Manufacturing Buildings Iron Concentration	94	0.3%
Ships and Barges Iron Concentration	92	0.3%
Major Bridges Iron Concentration	81	0.3%
Commercial HVAC Iron Concentration	79	0.2%
Heavy Trucks Iron Concentration, Weight, # Registrations	70	0.2%
Industrial Equipment Iron Concentration	42	0.1%
Commercial Shelving Iron Concentration, Weight	40	0.1%
Trailers Iron Concentration, Weight, # Registrations	37	0.1%
Commercial Shelving Aisle Spacing	36	0.1%
Manufacturing HVAC Iron Concentration	36	0.1%

Figure 2 In-use stocks results from various analyses



While not dramatic, the difference in iron stock results between the two methods is significant. There are several reasons to expect that the true per capita use of iron lies somewhere between the values resulting from the two types of analyses:

- The most obvious reason for the difference is that bottom-up studies can never capture all of the iron-containing products that exist. Each may only contain a small amount, but there are so many different products that the total of those neglected may be significant. Müller *et al.* (2006) report that 23% of the iron stock considered in their analysis is in machinery and appliances, whereas that category contributes only 9.5% to our bottom-up inventory (including HVAC equipment). However, this discrepancy could also be due to differences in the way the category has been defined.
- Top-down studies make use of lifetimes in order to calculate the in-use stock from annual metal inputs. Müller *et al.* (2006) assume that these lifetimes follow a normal distribution. However, lifetime distributions are often positively skewed with long tails. In the case of buildings it is impossible to tell the actual shape of the distribution before the majority of buildings in a given cohort have been demolished, which has not yet occurred in the United States sincer records have been kept. The assumption of normal lifetime distributions may tend to overestimate average product lifetimes and therefore also overestimate in-use stocks.
- There are a number of products that are counted in top-down studies but that do not actually exist within national (or state) borders. The first is military equipment used by the U.S. Armed Forces outside of the country. This equipment is never officially exported and so do not show up in trade data. A calculation of the iron existing in the U.S. Naval Fleet as well as armored vehicles and tanks was performed using data from Jane's Fighting Ships. The calculation revealed that these sub sectors represent a per capita iron stock of 27 kg. Clearly this is not a large percentage of the total, but other equipment and structures in overseas military bases may well contribute a more significant number. Top-down studies also capture ships that are bought by U.S. companies and are immediately registered under a foreign flag. Significant offshore iron stocks also exist in the form of oil and natural gas drilling platforms and their attendant infrastructure.
- Connecticut lacks many of the industries that use significant stocks of iron, such as oil and gas, steel production, and metal mining. In this way, it is not representative of the country as a whole. Agriculture in New England is on a small scale, necessitating less machinery than in the Midwestern states, for example. The contribution that these sectors make to the national top-down stocks is another possible reason for large discrepancy among the analyses.
- The issue of non-resident stock in the transportation sector is contentious, particularly for rail. Connecticut uses freight and passenger rail services

but contains a disproportionately small number of rail cars as stock, compared to the national average. The Association of American Railroads reports that there are 22,000 locomotives in Class I railroads in the United States. Scaling by population, Connecticut should contain about 226 freight locomotives, and yet the bottom-up approach captures only 33 locomotives.

- The approach of this study was to consider only those products providing services, ignoring those iron stocks in commerce. For example, refrigerators in domestic residences were accounted for, whereas refrigerators for sale in department stores were not. Similarly, iron stocks in used car lots and other mid-life commercial situations were not considered. Top-down models do not make this distinction and so again may overestimate the actual in-use stock.

It is useful to look at the breakdown by major category of iron stocks from the top-down and bottom-up analyses by mass. It must be noted that top-down studies use major, untested assumptions in the way iron stocks are partitioned into categories from trade data. Iron stock results for any given sector are thus less robust than the total result. Müller *et al.* (2006) separate iron stocks into four categories: Construction (which includes buildings and infrastructure), Machinery and Appliances, Transportation, and Other, which do not correspond with the categories used in this study. However, the detailed nature of bottom-up analyses enables U.S. to shift subcategories in order to match roughly the four top-down categories, thereby giving a coherent comparison:

Table 3 Comparison with Müller *et al.* (2006), by major category

Category	*Top-down Stocks (kg/c)*	*Bottom-up Stocks (kg/c)*
Structures	–	5027
Infrastructure	–	1287
Construction	**6000**	**6314**
HVAC	–	476
Equipment	–	486
Machinery & Appliances	**3600**	**962**
Transportation	**2600**	**1978**
Other	**800**	**–**

The largest discrepancy (by mass) is for the Machinery and Appliances category, while results for Construction match remarkably well. The "Other" category in the top-down study is not well defined and so cannot easily be matched to bottom-up categories.

Many significant refinements could be made to bottom-up calculations in order to improve their accuracy. The following are suggestions for future research:

1. Perform field studies to evaluate the types and quantities of machinery in different industries. Given that different manufacturing sectors can use vastly different machines, it is imprecise to extrapolate from textiles to food production, as was done here. Large machinery should also be closely considered, as well as any part of industrial buildings that are not structural or HVAC. Common equipment such as assembly lines, tables, and seating may contribute a surprising amount to the total iron stock.

2. Collect or perform further material-input studies for the buildings and construction sector in the United States. Residential, commercial, and industrial buildings should all be studied. Our analysis made some use of data from China and Korea, which may not be appropriate. It is necessary to refine these steel concentration factors as they have such a large effect on the total result, as seen in the sensitivity analysis.

3. Conduct a bottom-up analysis for the nation that would provide a direct comparison to top-down studies. Many statistics, including those for housing and transportation, are collected by the federal government and could easily be adapted for a national study. Other stock categories such as water distribution piping that are tracked on a municipal or regional level will require a different method than the company-by-company approach used here.

APPENDIX

The results for the Connecticut in-use stocks study are listed in Table A1, in both total mass and per capita terms. An error ranking is associated with each subcategory.

Table A1 Results of Connecticut bottom-up stocks study

Category	*Total Mass (Gg)*	*Per Capita (kg/c)*	*Error*
TOTAL IRON STOCK	31,700	9280	–
TRANSPORTATION (or mobile)	*6,740*	*1,978*	–
Automobiles	**5,640**	**1,655.5**	–
Cars	2,100	617.7	low
Light Trucks	2,310	677.3	low
Specialty and Large Trucks	701	205.9	medium
Trailers	371	108.9	low
Buses	100	29.2	low
Motorcycles, Snowmobiles, ATVs	9	2.7	low
Non-resident	47	13.7	low
Bicycles	**9**	**2.6**	medium
Air	**1**	**0.2**	–
in CT	1	0.1	low
Non-resident	0	0.0	low
Marine	**1,060**	**311.1**	–
in CT	379	111.3	medium
Non-resident	680	199.8	medium
Rail	**37**	**11.0**	–
in CT	34	10.0	low
Non-resident	3	1.0	low
BUILDINGS	*18,800*	*5,530*	–
RESIDENTIAL	4,180	1,226.3	–
Structures	**3,780**	**1,109.4**	–
Single Family	1,730	507.0	medium
Multi Family	478	140.3	medium
Apartment Buildings	1,560	458.1	high
Trailers	14	4.0	medium
HVAC	**370**	**108.6**	–
Heat Pumps	3	0.9	low
Gas-fired Furnaces	38	11.1	low
Oil-fired Boilers	117	34.3	low
Oil Tanks	99	29.0	low
Built-in Electric Heaters	4	1.3	low
Wood Stoves	3	0.8	low
Central Air Conditioning	13	3.7	medium
Radiators	24	6.9	medium
Chimney Liners	4	1.1	low
Water Heaters	66	19.3	low
Other	**28**	**8.3**	–
Kitchen Sinks	3	0.8	low
Garbage Disposals	3	0.9	low
Septic Tanks	22	6.6	high

COMMERCIAL	6,010	1,764.3	–
Structures	**5,080**	**1,493.0**	–
Masonry/Brick	1,340	394.0	high
Concrete	1,750	513.8	high
Steel	1,990	585.3	high
HVAC	**859**	**252.1**	–
Ventilation, Sprinklers	788	231.5	high
Heat Pumps	0	0.1	medium
Gas-fired Furnaces	7	1.9	medium
Oil-fired Boilers	17	5.1	medium
Space Heaters	0	0.0	medium
Packaged Heating Units	9	2.6	medium
Central Air Conditioning	0	0.1	medium
Central Chillers	1	0.3	medium
Packaged A/C Units	17	5.0	medium
Swamp Coolers	0	0.0	medium
Walk-in Freezers	1	0.2	medium
Built-in Refrigerated Cases	1	0.4	medium
Water Heaters	17	4.9	medium
Other	**65**	**19.2**	–
Commercial Sinks	56	16.3	medium
Elevators	10	2.9	low
INDUSTRIAL	8,650	2,539.1	–
Structures	**8,260**	**2,424.3**	–
Manufacturing	7,960	2,336.2	high
Power Plants	300	88.1	low
HVAC	**391**	**114.8**	–
Ventilation and Sprinklers	364	106.9	high
Heating	17	5.1	medium
Cooling	10	2.8	medium
EQUIPMENT	*1,660*	*486*	–
HOUSEHOLD ELECTRONICS AND APPLIANCES	389	114.3	–
"White Goods"	**254**	**74.7**	–
Refrigerators/Freezers	59	17.2	low
Washing Machines	43	12.7	low
Clothes Dryers	35	10.2	low
Dishwashers	16	4.8	low
Stoves/Domestic Cooking Ranges	68	20.1	low
Microwave Ovens	14	4.2	low
Portable Air Conditioners	19	5.6	medium
Electrical and Electronic	**20**	**5.9**	-
Computers	6	1.9	low
Televisions	9	2.6	low
Telephones	0	0.1	low
Stereos/Radios	3	0.8	medium
Fax Machines	0	0.1	low
Copiers	1	0.3	low
Sewing Machines	0	0.1	low
Irons	0	0.1	low

Other	**115**	**33.7**	–
Tableware	2	0.7	medium
Steel/tin Cans	3	0.8	low
Pots and Pans	5	1.6	low
Charcoal/Gas Grills	6	1.7	medium
Beds	39	11.4	medium
Filing Cabinets	26	7.7	low
Tools	16	4.7	high
Lawn Mowers	10	3.0	medium
Snow blowers	4	1.0	medium
Guns	4	1.1	low
COMMERCIAL ELECTRONICS AND APPLIANCES	627	184.2	–
"White Goods"	**71**	**20.9**	–
Refrigerators/Freezers	6	1.6	medium
Washing Machines	1	0.2	low
Clothes Dryers	1	0.3	low
Dishwashers	1	0.2	medium
Stoves/Ovens/Steamers	3	0.8	high
Microwave Ovens	0	0.1	medium
Portable Air Conditioners	59	17.4	high
Fryers	0	0.1	medium
Ice Machines	0	0.1	medium
Electrical and Electronic Equipment	**14**	**4.0**	–
Computers	6	1.6	medium
Televisions	0	0.1	high
Telephones	0	0.1	medium
Stereos/Radios	0	0.0	high
Copiers	8	2.3	medium
Other	**542**	**159.3**	–
Beds	1	0.4	medium
Filing Cabinets	16	4.5	medium
Shelving	432	126.7	high
Desks/Tables	7	2.2	high
Chairs	6	1.7	high
Restaurant Cooking Equipment	7	2.1	medium
Tableware	0	0.0	high
Automotive Tools	1	0.2	medium
Shopping Carts	15	4.3	high
Kegs	0	0.0	low
Laboratory Equipment and HVAC	17	5.1	high
Dumpsters	41	12.1	high
INDUSTRIAL MACHINERY AND APPLIANCES	640	187.9	–
Agriculture and Forestry	**26**	**7.5**	**high**
Transportation and Warehousing	**58**	**5.0**	–
Forklifts	17	5.0	medium
Shelving	41	11.9	medium
Manufacturing Equipment	**495**	**145.3**	–
Small	230	67.6	high
Large	186	54.6	high

Process Boilers	19	5.6	low
Shelving	57	16.8	high
Steel Drums	2	0.6	high
Construction	**62**	**18.2**	–
Vehicles	56	16.5	low
Cranes	5	1.5	high
Tools	1	0.3	high
INFRASTRUCTURE	***4,380***	***1,287***	–
Water Distribution	**1,660**	**487.2**	–
Supply and Distribution Mains	1,270	373.9	low
Hydrants	10	2.9	low
Service Connections	64	18.8	low
Pumps	1	0.3	low
Private Wells	311	91.3	medium
Gas Distribution	**294**	**86.4**	–
Mains	283	83.0	low
Service Connections	9	2.5	low
Meters	3	0.9	medium
Oil Storage and Distribution	**113**	**33.2**	–
Tanks	100	29.5	medium
Pipeline	13	3.7	low
Storm Sewers	**320**	**93.9**	–
Mains	309	90.8	medium
Manhole Covers	8	2.3	medium
Grates	3	0.9	medium
Streetscape	**145**	**42.7**	–
Signs	30	8.9	medium
Traffic Lights	11	3.2	medium
Street Lights	7	2.2	medium
Chain Link Fence	24	7.1	medium
Guard Rail	56	16.6	medium
Billboards	16	4.7	low
Rail	**357**	**104.8**	–
Track	326	95.6	low
Overhead Contact System	31	9.2	medium
Roads and Bridges	**882**	**259.1**	–
Reinforced Concrete Roads	14	4.0	medium
Bridges	869	255.1	medium
Electricity Transmission and Distribution	**481**	**141.1**	–
Cable	8	2.3	low
Towers	345	101.3	medium
Transformers	128	37.5	low
Telecommunications	**130**	**38.1**	–
Cable	0	0.0	low
Manholes	3	0.9	medium
Towers	127	37.3	low

ACRONYMS

AAR	Association of American Railroads
ARIC	Appliance Recycling Information Center
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BTS	Bureau of Transportation Statistics
CBECS	Commercial Buildings Energy Consumption Survey
CCEA	Connecticut Center for Economic Analysis
CTA	Center for Transportation Analysis
CT DEP	Connecticut Department of Environmental Protection
CT DOL	Connecticut Department of Labor
CT DOT	Connecticut Department of Transportation
CT DPH	Connecticut Department of Public Health
CT DPS	Connecticut Department of Public Safety
CT DPUC	Connecticut Department of Public Utility Control
EIA	Energy Information Administration
FHWA	Federal Highway Administration
HVAC	Heating, Ventilation, and Air Conditioning
JRCP	Jointed Reinforced Concrete Pavement
JEMAI	Japan Environmental Management Association for Industry
MECS	Manufacturing Energy Consumption Survey
NAICS	North American Industrial Classification System
NASS	National Agricultural Statistics Service
OPS	Office of Pipeline Safety
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WEEE	Waste Electrical and Electronic Equipment

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Industrial Ecology is an emerging field that focuses on the twin goals of economic development and environmental quality. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle–from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital.

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