Ch.2 Environmental Resources

Energy

Water

Materials

Energy

- Renewable sources: available indefinitely (for an unlimited or unspecified period of time) but arrive at a rate controlled by nature
  - solar radiation, wind, geothermal, woodlot
  - analogous to living on a fixed annual salary
- Non-renewable: once exhausted, cannot be replaced in a meaningful timeframe
  - coal, oil, natural gas
  - analogous to living off a one-time lottery win that can be spent in 1-50 years. when it is all spent, it is gone for good.

A fixed budget of renewable energy

- Problems
  - In 1830: population: less than 1 billion
    - Used renewable energy sources: fuel wood, work animals
  - Now: 6 billions more added
    - Use non-renewable energy sources: coal, oil, natural gas
  - In less than 200 years: 6 billion more people will be added to our planet

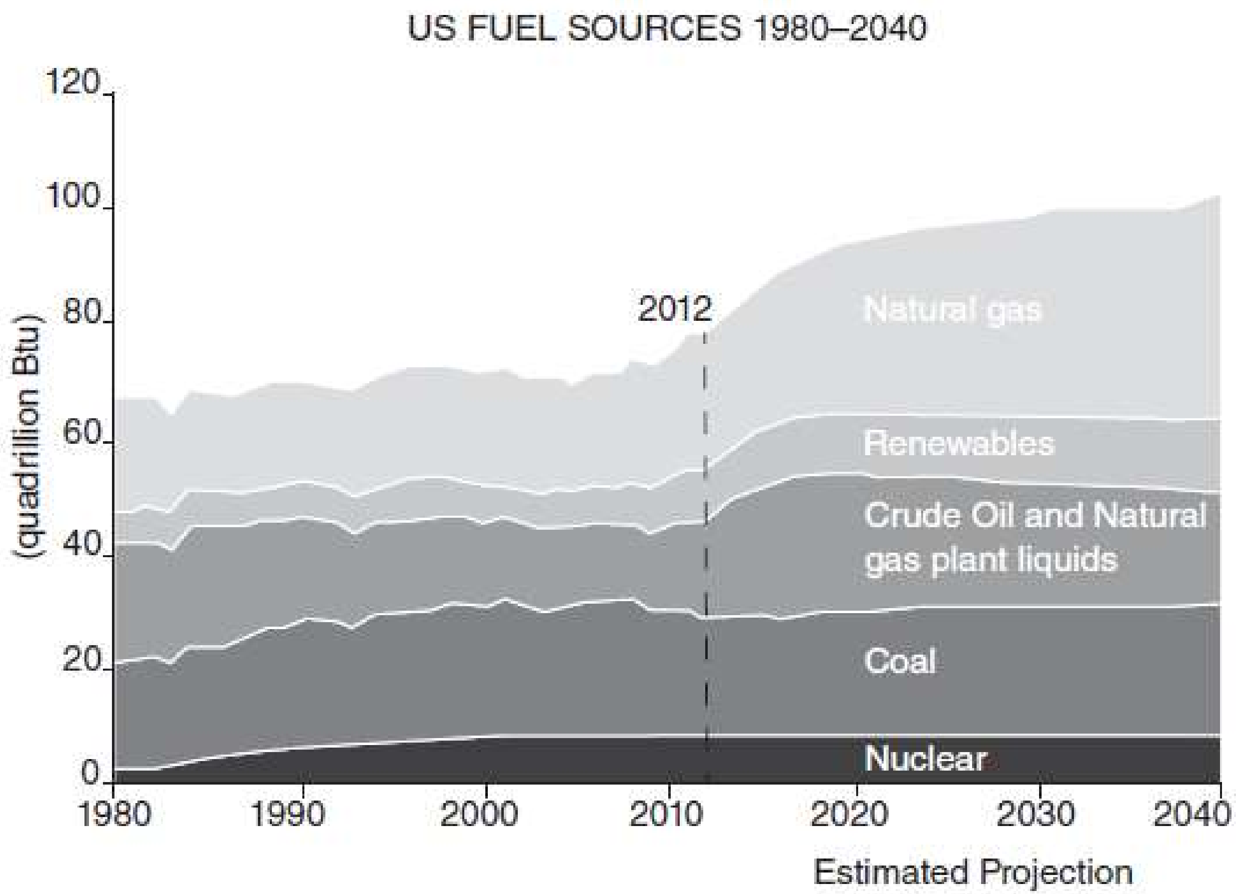
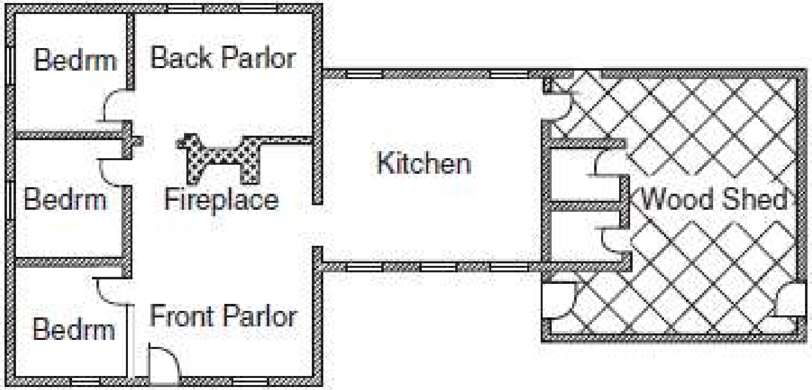
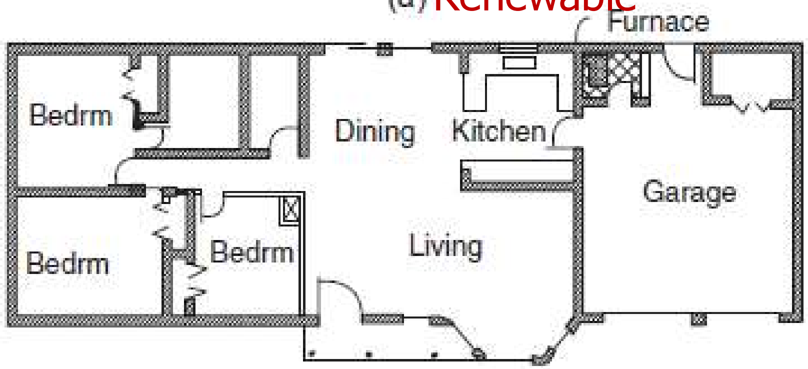


Fig. 2.1 *U.S. fuel sources since 1850, showing a progression from dependence on renewable energy (wood and work animals) to fossil fuels (coal, then oil and gas). Wind and water power were shifted from mills to electricity generation between 1890 and the present. Although not shown here, much fossil fuel is now converted to electricity before use. (Data 1850–1950 are from Fisher, 1974; data 1951–2011 are from U.S. Energy Information Administration, 2012; Drawn by Sharon Alitema.)*



(a) Renewable



(b) Non-renewable

Fig. 2.2 Residential heating: past and present. (a) The house dependent on fireplaces or wood stoves also depends on someone to tend the fire. The warmer area near the fire in this early Oregon farmhouse was used for social purposes; the colder extremities served as sleeping areas and for storage of food and fuel. (Based upon a plan drawn by Philip Dole.) (b) The contemporary suburban home has either a small area for heating/cooling equipment or electric heat built into each room. Climate control equipment is no longer a major influence on building form.

Fig. 2.3 The fireplace and the more efficient wood stove can inspire architectural form. This chimney symbolizes permanence as well as protection against the cold. The major social space of the house is marked both by the arched window and by the fireplace chimney. (Photo by William Johnston.)

NGPL: Natural gas plant liquids

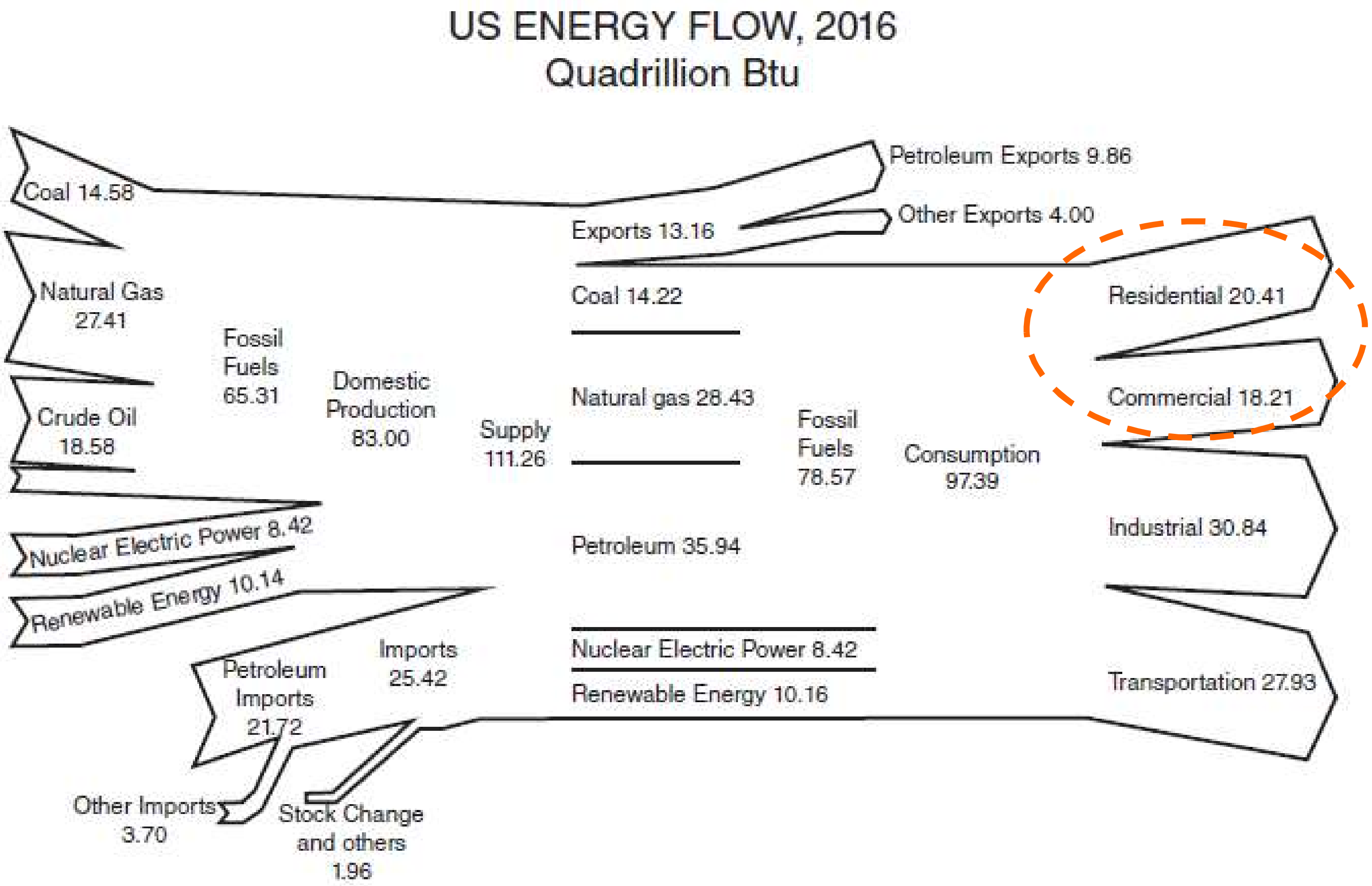


Fig. 2.4 U.S. energy flow, 2016: sources and end uses. This data is updated on a regular basis, but the general patterns shown in this figure change slowly. Fuel types and sources are shown to the left and end use sectors to the right. Note the importance of residential and commercial consumption to total U.S. consumption—and the currently minuscule contribution of renewable energy sources to the whole. (Redrawn by Sharon Alitema using data from the U.S. Energy Information Administration, U.S. Department of Energy, Annual Energy Review, *2017.)*

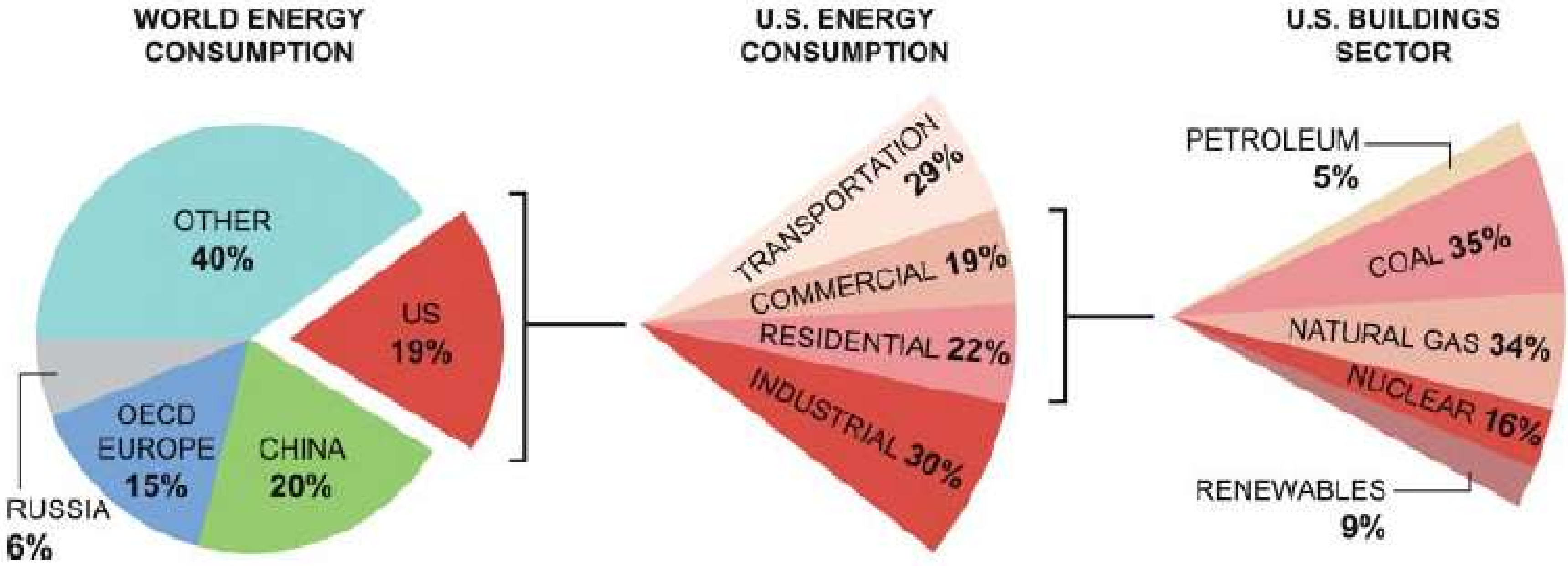


Fig. 2.5 *Energy resources as consumed by various end-use sectors in the United States, 2012. (Data and graphic from the USDOE's* 2011 Buildings Energy Data Book.*)*

Modern buildings rely too heavily on electricity

- For some primary energy sources (coal, fuel oil, nuclear) to be distributed to buildings, electricity is the only convenient usage option.
- Electricity is the only source for building illumination
- Mechanical cooling is almost universal
- Electricity is a convenient and versatile energy form: lighting, water heating, space heating, cooking, motors
- But, the efficiency in generation and delivery ??? ☹ (Fig. 2.6)

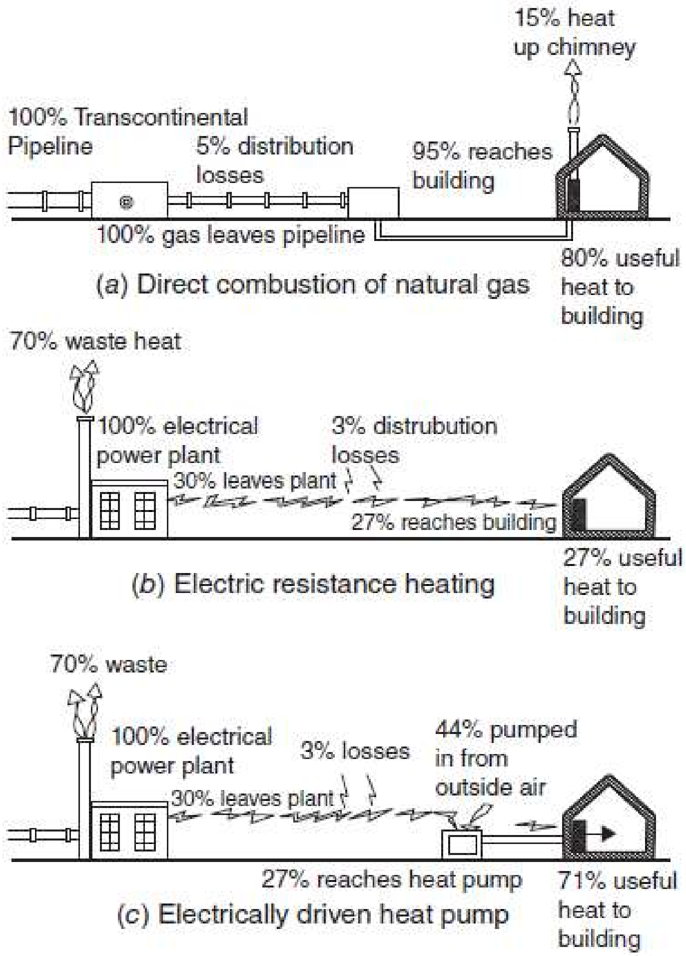


Fig. 2.6 *Variations on higher-grade energy and lower-grade tasks. (a) Natural gas (a fossil fuel) is often burned in furnaces to provide low-grade space heating. With today's high-efficiency furnaces, well over 90% of the energy in the gas is delivered to the building as space heat. (b) However, when that natural gas is used instead to generate electricity, and electric resistance is used for space heating, the inefficiencies at the electric power plant cut deeply into the available useful energy: Only about 27% is delivered to the space as heat. (c) On the other hand, when the electricity generated by natural gas is used to drive a heat pump, and the outdoor air is above freezing, about 71% of the energy in the gas is delivered as space heat. (Drawing by Michael Cockram; © by John S. Reynolds; all rights reserved.)*

TABLE 2.1 Energy End Use in U.S. Buildings, by Fuel Type (Quads)[a]

End Use	Natural Gas	Fuel Oil[b]	LPG	Other Fuel[c]	Renewable Energy[d]	On-Site Electric	On-Site Total	On-Site %	Primary Electric[e]	Primary Total	Primary %
Space heating[f]	5.14	0.76	0.30	0.10	0.54	0.72	7.56	37.0	2.24	9.07	22.5
Space cooling	0.04					1.92	1.96	9.6	5.94	5.98	14.8
Ventilation[g]						0.54	0.54	2.6	1.66	1.66	4.1
Water heating	1.73	0.13	0.07		0.04	0.54	2.51	12.3	1.67	3.63	9.0
Lighting						1.88	1.88	9.2	5.82	5.82	14.4
Refrigeration[h]						0.84	0.84	4.1	2.62	2.62	6.5
Cooking	0.39		0.03			0.21	0.63	3.1	0.64	1.06	2.6
Wet clean[i]	0.06					0.33	0.38	1.9	1.01	1.06	2.6
Computers						0.38	0.38	1.9	1.19	1.19	2.9
Electronics						0.81	0.81	3.9	2.49	2.49	6.2
Other[j]	0.30	0.01	0.30	0.05	0.02	0.89	1.58	7.7	2.76	3.45	8.6
Adjustments[k]	0.68	0.25				0.44	1.37	6.7	1.35	2.28	5.7
Total	8.35	1.14	0.70	0.15	0.59	9.49	20.43	100	29.39	40.33	100

A B C=3.22*A D=B+C-A

Source: U.S. DOE (2012). Data are for the year 2011.

[a]Quad = 10^{15} Btu (1 Ej).

[b]Includes distillate fuel oil (1.38 quads) and residual fuel oil (0.08 quad).

[c]Kerosene (0.08 quad) and coal (0.11 quad) are assumed to be attributed to space heating; motor gasoline (0.05 quad) is assumed to be attributed to "other" end uses.

[d]Passive solar space heating is not included. This column includes wood space heating (0.39 quad), geothermal space heating (<0.01 quad), solar water heating (0.05 quad), biomass (0.01 quad), and solar PV (<0.01 quad).

[e]Site-to-source electricity conversion = 3.22 due to generation and transmission losses.

[f]Includes electric furnace fans (0.25 quad).

[g]Commercial only (residential fan and pump energy use included proportionally in space heating and cooling).

[h]Includes refrigerators (1.37 quads) and freezers (0.43 quad) and commercial refrigeration.

[i]Includes clothes washers (0.10 quad), natural gas clothes dryers (0.07 quad), electric clothes dryers (0.76 quad), and dishwashers (0.08 quad).

[j]Includes commercial service station equipment, emergency electric generators, fuel oil cooking, natural-gas-driven pumps, natural gas lighting, automated teller machines, telecommunications equipment, medical equipment, residential pool/hot tub heating, residential small electric devices, outdoor grilles, outdoor natural gas lighting, and the like.

[k]Energy Information Administration (EIA) adjustment to address discrepancies among data sources. Energy is attributable to the residential and commercial buildings sector, but not directly to specific end uses.

너무 싸 전기 과소비?… 시름 깊은 정부

비싼 원유 수입해 전기생산… 에너지 왜곡 초래

회사원 박모 씨(33)는 지난해 11월 서울 종로구 옥인동으로 이사했다. 이곳은 도시가스가 들어오지 않아 대부분의 주민들이 기름보일러를 사용해 왔다. 박 씨도 처음엔 기름보일러를 사용했지만 한 달에 약 25만 원이나 되는 기름값이 부담스러웠다. 박 씨는 부담을 덜기 위해 전기 패널 2장(3.3m² 크기)을 설치했다. 하루 8시간 정도 사용하는데 전기료는 10만 원 안쪽. 두 달이면 기름보일러를 사용할 때보다 구입비와 시공비(약 30만 원)만큼을 절약할 수 있는 셈이다.

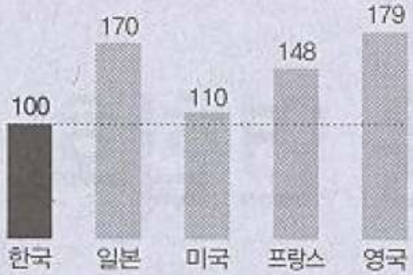
개인적 관점에서 보면 박 씨는 현명한 선택을 했다. 하지만 국가 전체적으로 봐도 현명한 선택일까.

● 값싼 전기료가 불러온 '에너지 왜곡'

2002년부터 지난해까지 등유 가격은 L당 연평균 123.6%, 경유는 138.1% 올랐다. 하지만 전기료는 5.8% 오르는 데 그쳤다. 전기료가 싸지자 국민들은 전기 소비를 늘렸다. 같은 기간 등유와 경유(전기와 대체재가 아닌 수송용 경유 제외) 소비는 각각 52.7%, 9.8% 줄었지만 전기 소비는 38.3% 늘었다. 특히 화훼 및 축산 농가, 상가 주인들이 기름 난방을 전기난방으로 앞 다퉈 교체했다. 물류업계는 각종 하역장비를 경유 구동방식에서 전기식으로 개조하는 추세다. 2007년 기준 한국 제조업의 국내총생산(GDP) 대비 전기 소비량도 경제협력개발기구(OECD) 주요국의 1.4~2.2배로 높다.

문제는 전기 사용은 '에너지 왜곡'을 불러온다는 점이다. 한국개발연구원(KDI)에 따르면 등유나 경유, 액화천연가스(LNG) 등 1차 에너지를 열로 바꾸면 약 80%의 효율을 올릴 수 있다. 하지만 1차 에너지를 발전소에서 전기로 만들어 전기보일러로 난방을 하면 효율은 약 35%로 줄어든다. 특히 발전(發電)할 때 1차 에너지의 약 60%가 사라진다. 원자력을 제외하고 1차 에너지로 전기를 만드는 것은 전체 발전량의 약 60%다.

국내외 전기료 비교



한국 전기료를 100으로 봤을 때 외국의 전기료 2007년 전기료 기준(프랑스는 2006년)이고, 당시 환율 적용. 자료 : 한국전력공사

KDI는 1차 에너지를 전기로 바꿔 난방을 하는 바람에 연간 9000억 원의 손실을 보고 있다고 추정했다. 게다가 난방은 시설투자 때문에 약 10년을 지속해 사용하는 특징이 있어 에너지 왜곡은 갈수록 커지고 있다. 정한경 에너지경제연구원 선임연구위원은 "한국은 에너지를 전량 수입하는데 전기료가 싸다 보니 국민이 전기 과소비를 하는 경향이 있다"며 "이는 원유 수입을 늘리게끔 해 무역수지를 악화시키고 경기회복에 악영향을 미칠 수 있다"고 지적했다.

● 깊어지는 정부의 고민

한국의 전기료는 2007년 기준으로 일본의 59%, 영국의 56%에 불과하다. 값싼 전기료는 몇 년 후 소비자에게 칼날로 되돌아올 가능성도 있다.

이런 이유 때문에 주무부처인 지식경제부의 고민은 깊어만 가고 있다. 전기사업법 등에 따르면 전기 사용의 주무 부처(지경부) 장관이 물가 관련 부처(기획재정부)와 협의를 거쳐 최종적으로 전기료 인상·인하를 인가하도록 돼 있다.

이윤호 지경부 장관도 3월 18일 서울 롯데호텔에서 열린 '녹색성장 산업의 비전과 발전전략' 강연에서 "에너지가격 메커니즘이 효율적으로 작동하도록 하기 위해선 경기가 회복되는 기미가 보이면 전기료를 올릴 수밖에 없는 상황"이라고 말했지만 구체적인 시기는 밝히지 않았다.

박형준 기자 lovesong@donga.com

Solar energy

- An oil company predicted that 50% of world energy demand will be met by alternatives to fossil fuels by year 2050.
  - PV(photovoltaic)

TABLE 2.2 Daily Arrival of Solar Energy on Earth Compared to Other Energy Quantities

Solar energy received each day	1
Melting of an average winter's snow during the spring	1/10
A monsoon's circulation between ocean and continent	1/100
Use of energy by all mankind in a year	1/100
A mid-latitude cyclone	1/1000
A tropical cyclone	1/10,000
Kinetic energy of motion in Earth's general circulation	1/100,000
The first hydrogen bomb	1/100,000
A squall line containing severe thunderstorms	1/1,000,000
A thunderstorm	1/100,000,000
The first atomic bomb	1/100,000,000
The daily output of Boulder Dam	1/100,000,000
A typical local rain shower	1/10,000,000,000
A tornado	1/100,000,000,000
Lighting New York City for one night	1/100,000,000,000

Source: Reprinted by permission from Lowry, W. 1988. *Atmospheric Ecology for Designers and Planners*. McMinnville, OR: Peavine Publications.

Water

- Water concerns are at crisis level, and will be the emerging limit to growth and development
  - Fresh water: surface water, underground water
  - Saline water
- Use: agricultural use & power generation
- Two problems:
  - Problem #1: Water is a recyclable(재활용) resource, but it is not a renewable resource: All the water that will ever be is, right now. (Depletion of underground water stocks from aquifers is analogous to fossil fuel reserves)
    - purified water: which can be extracted or obtained from basically any source.
    - natural mineral water: filtered by sand and stone of various sizes.
    - Hydrologists estimate that the water in some aquifers is more than 10,000 years old (https://www.livescience.com/39625-aquifers.html)
  - Problem #2: Where the water is, is not necessarily where it is wanted.
- Lack of 'water-use efficiency' concept: compared to energy
  - Water efficiency standards are not nearly as extensive or ubiquitous as energy-efficiency standard

Materials

- Trends in per capita consumption of materials
  - Early 1900s: 3.0 tons per person (50% for construction)
  - In 1950: 6.0 tons per person (60% for construction)
  - In 1995: 10.0 tons per person (65% for construction)
- Selections
  - imported vs. local materials
    - imported = not necessarily from overseas, transported from a distance, not local
  - virgin vs. recycled materials
    - Virgin material: has not been previously used or consumed
  - renewable vs. nonrenewable
  - Choice: between imported renewable and local nonrenewable materials
- Reducing the transportation distance and finding local materials are emerging design strategies.

Wood is…

- The only renewable construction material widely used in U.S. (easily worked, good for finishes, moderate structural strength, moderate as thermal mass or insulation)

Nonrenewable materials

- Metals, plastics: commonly used in mechanical and electrical systems in buildings
- come with a significant energy cost to mine/manufacture, transport, shape them for use.
- Metals/plastics = recyclable and nonrenewable.

Embodied energy (내재 에너지)

- Indicator of how much energy must be invested to mine/harvest/produce, fabricate, and transport a unit of building material
- Variations
  - in availability of raw resource
  - in distance from raw resource to manufacturing locations
  - in the fuel used

equivalent CO_2 (CO_2e)

TABLE 2.4 Approximate Total Embodied Energy and Carbon in Building Materials[a]

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - $kgCO_2/kg$	EC - $kgCO_2e/kg$	EE = Embodied Energy EC = Embodied Carbon
Asphalt				
Asphalt, 4% (bitumen) binder content (by mass)	2.86	0.059	0.066	1.68 MJ/kg Feedstock Energy. Modeled from the bitumen binder content. The fuel consumption of asphalt mixing operations was taken from the Mineral Products Association (MPA). It represents typical UK industrial data. Feedstock energy is from the bitumen content.
Bitumen	51	0.38–0.43	0.43–0.55	42 MJ/kg Feedstock Energy. Feedstock assumed to be typical energy content of Bitumen. CO_2 emissions are particularly difficult to estimate, range given.
Bricks				
General (Common Brick)	3.00 (6.9 MJ per brick)	0.23 (0.53 $kgCO_2$ per brick)	0.24 (0.55 $kgCO_2$ per brick)	Assuming 2.3 kg per brick
Limestone	0.85			
Carpet				
General Carpet	74 (187 per sqm)	3.9 (9.8 per sqm)		
Wool	106.00	5.53		
Cement				
General (UK weighted average)	4.5	0.73	0.74	Weighted average of all cement consumed within the UK. This includes all factory-made cements (CEM I, CEM II, CEM III, CEM IV) and further blending of fly ash and ground granulated blast furnace slag. This data has been estimated from the British Cement Association's factsheets. 23% cementitious additions on average.
Clay				
General (Simple Baked Products)	3.00	0.23	0.24	General simple baked clay products (incl. terracotta and bricks).
Tile	6.50	0.45	0.48	
Vitrified clay pipe DN 100 & DN 150	6.20	0.44	0.46	
Concrete				
General	0.75	0.100	0.107	It is strongly recommended to avoid selecting a "general" value for concrete. Selecting data for a specific concrete type (often a ready-mix concrete) will give greater accuracy; please see material profile. Assumed cement content 12% by mass.
CONCRETE BLOCKS (ICE CMC Model Values)				
Block - 8 MPa Compressive Strength	0.59	0.059	0.063	Estimated from the concrete block mix proportions, plus an allowance for concrete block curing, plant operations, and transport of materials to factory gate.
Block - 10 MPa	0.67	0.073	0.078	
Block - 12 MPa	0.72	0.082	0.088	
Block - 13 MPa	0.83	0.100	0.107	
Autoclaved Aerated Blocks (AAC's)	3.50	0.24 to 0.375	0.107	Not ICE CMC model results.

TABLE 2.4 Approximate Total Embodied Energy and Carbon in Building Materials (*continued*)

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - $kgCO_2/kg$	EC - $kgCO_2e/kg$	EE = Embodied Energy EC = Embodied Carbon
Glass				
Primary Glass	15.00	0.86	0.91	Includes process CO_2 emissions from primary glass manufacture.
Secondary Glass	11.50	0.55	0.59	
Toughened	23.50	1.27	1.35	Only three data sources.
Insulation				
General Insulation	45.00	1.86		Estimated from typical market shares. Feedstock Energy 16.5 MJ/kg.
Cellular Glass	27.00			
Cellulose	0.94 to 3.3			
Cork	4.00	0.19		
Fiberglass (Glasswool)	28.00	1.35		Poor data difficult to select appropriate value.
Mineral Wool	16.60	1.20	1.28	
Paper Wool	20.17	0.63		
Polystyrene	See Plastics.	See Plastics.		See Plastics.
Polyurethane	See Plastics.	See Plastics.		See Plastics.
Rockwool	16.80	1.05	1.12	Cradle to Grave
Woodwool (Loose)	10.80			
Woodwool (Board)	20.00	0.98		
Wool (Recycled)	20.90			
Linoleum	25.00	1.21		Data difficult to select, large data range.
Paint				
General	70.00			Large variations in data, especially for embodied carbon. Includes feedstock energy. Water-based paints have a 70% market share. Water-based paint has a lower embodied energy than solvent-based paint.
EXAMPLE: Single Coat	10.50 MJ/Sqm	0.36 $kgCO_2$/Sqm	0.44	Assuming 6.66 Sqm Coverage per kg
EXAMPLE: Double Coat	21.00 MJ/Sqm	0.73 $kgCO_2$/Sqm	0.87	Assuming 3.33 Sqm Coverage per kg
Plaster				
General (Gypsum)	1.80	0.12	0.13	Problems selecting good value, inconsistent figures, West et al. believe this is because of past aggregation of EE with cement.
Plastics				
General	80.50	2.73	3.31	35.6 MJ/kg Feedstock Energy (Included). Determined by the average use of each type of plastic used in the European construction industry.
ABS	95.30	3.05	3.76	48.6 MJ/kg Feedstock Energy
PVC General	77.20	2.61	3.10	28.1 MJ/kg Feedstock Energy. Based on market average consumption of types of PVC in the European construction industry.
PVC Pipe	67.50	2.56	3.23	24.4 MJ/kg Feedstock Energy. If biomass benefits are included the CO_2 may reduce to 2.51 $kgCO_2/kg$, and GWP down to 3.23 kg CO_2e/kg.

Comparative study: embodied energy

- Exterior wall cladding: wood and aluminum siding
  - Wood: cut, transport, process……
  - Aluminum: mine, melt, transport….
- Aluminum consumes 100 times as much embodied energy as the wood for a given surface area of finished siding.
- Needs to consider maintenance, replacement needs and schedules, relation to building energy

Recycled or virgin material

- 1998 EPA (US Environmental Protection Agency) report: 136 million tons is produced and 65-85% of that total ends up with landfills
- The recovery of usable materials from demolition is limited because of high labor cost.
- Due to lack of landfill capacity and design regulations, recycling examples are numerous.

TABLE 2.5 Residential Salvage for Reuse

	Embodied Energy[a] Btu/ft² Floor Area (kJ/m² Floor Area)	Value U.S. \$/ft² Floor Area (U.S. \$/m² Floor Area)
Total for reusable salvage[b]	46,890 (532,497)	4.90 (52.74)
Demolition energy consumed[c]	−3,380 (−38,384)	
Value of energy embodied in salvage[d]		+0.50 (5.38)
Value of avoided dumping fees		+2.70 (29.06)
Total energy savings and value	43,510 (494,112)	8.10 (87.19)

Source: Joslin et al. (1993).

[a]Based on Stein et al. (1981).

[b]Framing lumber alone constituted 38% of this embodied energy.

[c]Gasoline for transportation and hauling, plus human labor at 254.6 Btu/h (268.6 kJ/h).

[d]Assumed at $.04/kWh, a very low rate typical of the Pacific Northwest.

494,112 kJ/m² = 137.3 kWh/m²

Design challenges

- In terms of building's operation, energy sources, water and embodied materials
  - Design for building recycling
  - Design for energy transition
  - Design for information age
  - Design for transportation

Design for building recycling

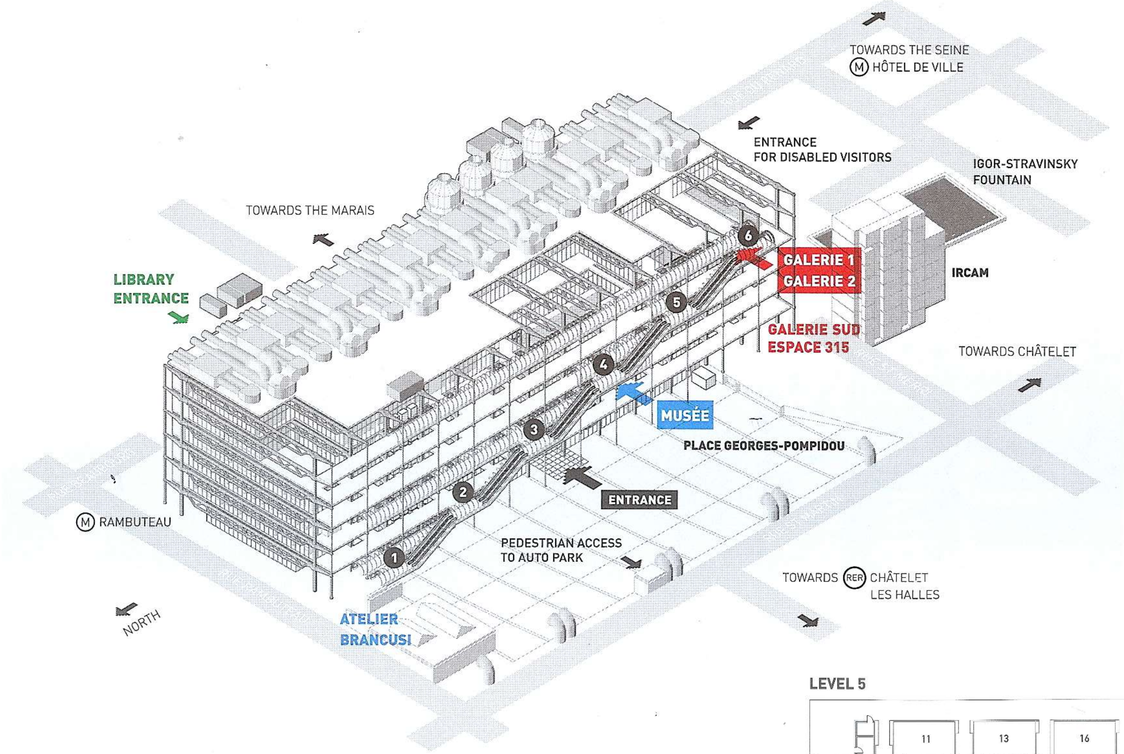
- Two points:
  - Enough flexibility not to demolish a building (easily adaptable to changed usage)
  - Allowing for demounting of parts
    - A new research initiative in European countries to disintegrate mechanical and structural systems
- Current issue in AEC
  - rebuilding (재건축) vs. remodeling (리모델링)

Guidelines for recyclable buildings

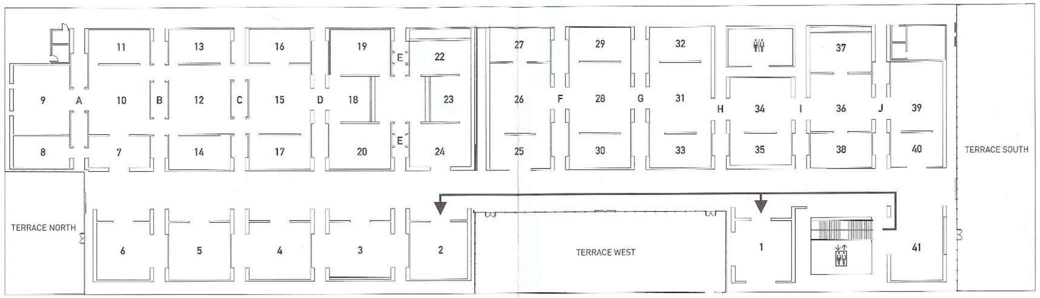
- Design the structure separable from everything else
  - Extensive remodeling is then possible without major structural modifications.
- Design for ‘breathing room’
  - Expandable without rebuilding
  - Columns and footings to support an extra floor or two for vertical expansions
- Maximize the use of natural on-site forces (wind, sun, daylight):
  - the less sophisticated MEP, the less obvious the obsolescence of MEP
- Avoid combinations that make recycling difficult
  - e.g., a steel or plastic pipe embedded in a concrete slab, sandwiches (metals, plastics, other products).

Pompidou

- Architects: Renzo Piano & Richard Rogers
- Year constructed: 1977



LEVEL 5



LEVEL 4