From: "O'Rourke, Daniel J." <danorourke@anl.gov>
To: "Samuel Hernandez-Quinones" <SHQ@nrc.gov>, "Richard Emch" <RLE@nrc.gov>, "Miller, David S." <david.s.miller@anl.gov>
Date: 12/12/2006 5:32:48 PM
Subject: FW: VT Yankee Alternative PDF References

Sam,

Attached are pdf's of the webpages used in the Vermont Yankee Alternatives chapter.

Dan

> ____
> From: Moret, Ellen N.
> Sent: Tuesday, December 12, 2006 2:29 PM
> To: O'Rourke, Daniel J.
> Subject: VT Yankee Alternative PDF References
>
> <<Efficiency Vermont Program.pdf>> <<Obstruction Marking and
> Lighting.log.pdf>> <<Coal Combustion-Nuclear Resource or Danger.pdf>>
> <<Wind Farm Area Calculator.pdf>> <<U.S. Wind Energy Resource
> Map.pdf>> <<Vermont Wind Activities.pdf>> <<Alternative Energy
> Resources in Vermont.pdf>> <<Phosphoric Acid Fuel Cells.pdf>> <<Fuel
> Cells Powering America.pdf>> <<Municipal Solid Waste.pdf>>
> <<Mercury--Controlling Power Plant Emissions-Overview.pdf>> <<NRC
> Organizes Future Licensing Project Organization.pdf>> <<Biomass
> Feedstock Availability in the United States.pdf>>

CC: "Moret, Ellen N." <moret@anl.gov>, "Wescott, Konstance L." <wescott@anl.gov>

Mail Envelope Properties (457F2DF4.1DB : 13 : 475)

Subject: FW: VT Yankee Alternative PDF References
Creation Date 12/12/2006 5:31:22 PM
From: "O'Rourke, Daniel J." <danorourke@anl.gov>

Created By: danorourke@anl.gov

Recipients
nrc.gov
TWGWPO03.HQGWDO01
SHQ (Samuel Hernandez-Quinones)

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anl.gov
wescott CC (Konstance L. Wescott)
moret CC (Ellen N. Moret)
david.s.miller (David S. Miller)

Post Office	Route
TWGWPO03.HQGWDO01	nrc.gov
OWGWPO02.HQGWDO01	nrc.gov
	anl.gov

Files	Size	Date & Time
MESSAGE	936	12/12/2006 5:31:22 PM
TEXT.htm	2656	
Efficiency Vermont Program.pdf	77679	
Obstruction Marking and Lighting.log.pdf	5084533	
Coal Combustion-Nuclear Resource or Danger.pdf	183199	
Wind Farm Area Calculator.pdf	62082	
U.S. Wind Energy Resource Map.pdf	83905	
Vermont Wind Activities.pdf	103813	
Alternative Energy Resources in Vermont.pdf	88933	
Phosphoric Acid Fuel Cells.pdf	120890	
Fuel Cells Powering America.pdf	809308	
Municipal Solid Waste.pdf	64597	
Mercury--Controlling Power Plant Emissions-Overview.pdf	34065	
NRC Organizes Future Licensing Project Organization.pdf	30601	
Biomass Feedstock Availability in the United States.pdf	125601	
Mime.822	9409676	

Options

Expiration Date:	None
Priority:	Standard
ReplyRequested:	No
Return Notification:	None
Concealed Subject:	No
Security:	Standard

Junk Mail Handling Evaluation Results

Message is eligible for Junk Mail handling
This message was not classified as Junk Mail

Junk Mail settings when this message was delivered

Junk Mail handling disabled by User
Junk Mail handling disabled by Administrator
Junk List is not enabled
Junk Mail using personal address books is not enabled
Block List is not enabled

Efficiency Vermont

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- Weil-McLain Recalls Ultra Series Boilers for Carbon Monoxide Hazard
- Learn About Home Performance Training Sessions
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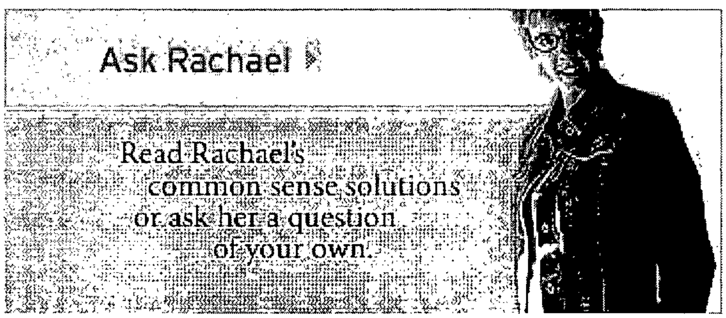


What's New

Efficiency Vermont in the News
Vermont Collegiate Change a Light Challenge
Residential Green Building Workshop

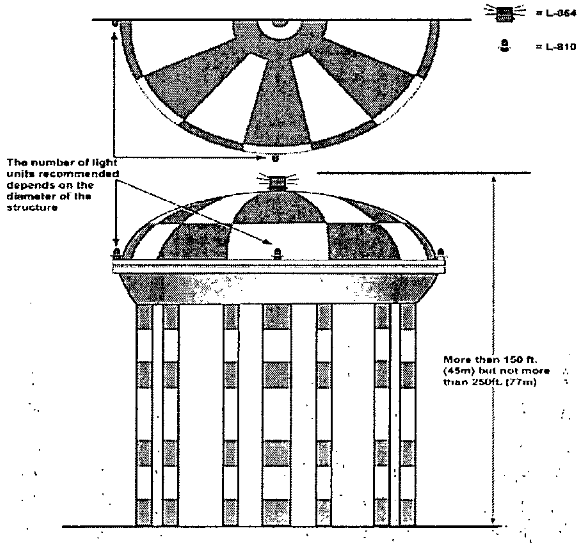
For more information, call 802-860-4095, or call toll-free 1-888-921-5990.
Please contact us with comments, questions or suggestions.

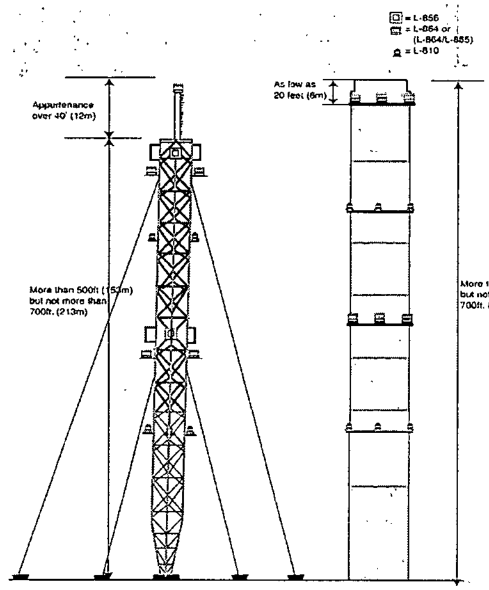
U.S. Department
of Transportation
**Federal Aviation
Administration**

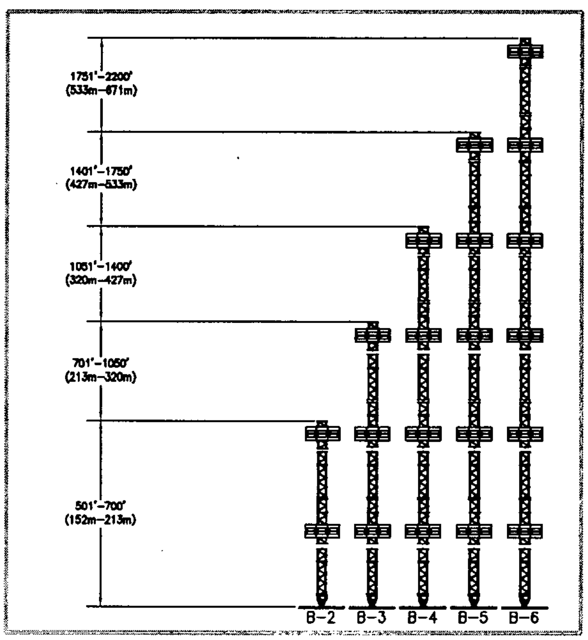
ADVISORY CIRCULAR

AC 70/7460-1K

Obstruction Marking and Lighting







Effective: 8/1/00

Prepared by the Air Traffic Airspace Management

U.S. Department
Of Transportation
Federal Aviation Administration

ADVISORY CIRCULAR

Subject: CHANGE 1 TO OBSTRUCTION MARKING AND LIGHTING

Date: 4/15/00
Initiated by: ATA-400

AC No: 70/7460-1K
Change: 1

1. PURPOSE. This change amends the Federal Aviation Administration's (FAA) standards for marking and lighting structures to promote aviation safety. The Change Number and date of the change material are located at the top of the page.

2. EFFECTIVE DATE. This change is effective August 1, 2000.

3. EXPLANATION OF CHANGES.

   a. Table of Contents. Change pages i through iii.

   b. Change pages 19 through 32 beginning at Chapter 7. High Intensity Flashing White Obstruction Light Systems to read 21 through 34.

   c. Page 1. Paragraph 1. **Reporting Requirements**. Owner changed to read sponsor.

   d. Page 1. Paragraph 5. **Modifications and Deviations**. Owner changed to read sponsor.

   e. Page 1. Paragraph 5.b.3. **Voluntary Marking and/or Lighting**. Owner/s changed to read sponsor.

   f. Page 2. Paragraph d. Chapter 6 changed to read Chapter 12, Table 4.

   g. Page 2. Paragraph d. Owners/proponents changed to read sponsors.

   h. Page 2. Paragraph 6. **Additional Notification**. Proponents changed to read sponsors.

   i. Page 2. Paragraph 7. **Metric Units**. Proponents changed to read sponsors.

   j. Page 3. Paragraph 23. **Light Failure Notification**. Proponents changed to read sponsors.

   k. Page 4. Paragraph 24. **Notification of Restoration**. Owner changed to read sponsor.

   l. Page 7. **Note**. Change proponents to read sponsors.

m. Page 11. Paragraph 49. **Distraction**. Owner changed to read sponsor

n. Replace Pages A1-1 through A1-19. New illustrations. In addition, mid-level lighting on structures beginning at 250 feet above ground level (AGL) has been corrected to reflect lighting beginning at 350 feet AGL.

for JOHN S. WALKER
Program Director for Air Traffic
Airspace Management

PAGE CONTROL CHART

AC 70/7460-1K, CHG. 1

Remove Pages	Dated	Insert Pages	Dated
i through iii	3/1/00	i through iii	8/1/00
1 through 4	3/1/00	1 through 4	8/1/00
7	3/1/00	7	8/1/00
11	3/1/00	11	8/1/00
A1-1 through A1-19	3/1/00	A1-1 through A1-19	8/1/00

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CHAPTER 5. RED OBSTRUCTION LIGHT SYSTEM

CHAPTER 6. MEDIUM INTENSITY FLASHING WHITE OBSTRUCTION LIGHT SYSTEMS

CHAPTER 7. HIGH INTENSITY FLASHING WHITE OBSTRUCTION LIGHT SYSTEMS

CHAPTER 8. DUAL LIGHTING WITH RED/MEDIUM INTENSITY FLASHING WHITE SYSTEMS

CHAPTER 9. DUAL LIGHTING WITH RED/HIGH INTENSITY FLASHING WHITE SYSTEMS

CHAPTER 10. MARKING AND LIGHTING OF CATENARY AND CATENARY SUPPORT STRUCTURES

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CHAPTER 12. MARKING AND LIGHTING EQUIPMENT AND INFORMATION

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CHAPTER 1. ADMINISTRATIVE AND GENERAL PROCEDURES

1. REPORTING REQUIREMENTS

A sponsor proposing any type of construction or alteration of a structure that may affect the National Airspace System (NAS) is required under the provisions of 14 Code of Federal Regulations (14 CFR part 77) to notify the FAA by completing the Notice of Proposed Construction or Alteration form (FAA Form 7460-1). The form should be sent to the FAA Regional Air Traffic Division office having jurisdiction over the area where the planned construction or alteration would be located. Copies of FAA Form 7460-1 may be obtained from any FAA Regional Air Traffic Division office, Airports District Office or FAA Website at www.faa.gov/ats/ata/ata400.

2. PRECONSTRUCTION NOTICE

The notice must be submitted:

a. At least 30 days prior to the date of proposed construction or alteration is to begin.

b. On or before the date an application for a construction permit is filed with the Federal Communications Commission (FCC). (The FCC advises its applicants to file with the FAA well in advance of the 30-day period in order to expedite FCC processing.)

3. FAA ACKNOWLEDGEMENT

The FAA will acknowledge, in writing, receipt of each FAA Form 7460-1 notice received.

4. SUPPLEMENTAL NOTICE REQUIREMENT

a. If required, the FAA will include a FAA Form 7460-2, Notice of Actual Construction or Alteration, with a determination.

b. FAA Form 7460-2 Part 1 is to be completed and sent to the FAA at least 48 hours prior to starting the actual construction or alteration of a structure. Additionally, Part 2 shall be submitted no later than 5 days after the structure has reached its greatest height. The form should be sent to the Regional Air Traffic Division office having jurisdiction over the area where the construction or alteration would be located.

c. In addition, supplemental notice shall be submitted upon abandonment of construction.

d. Letters are acceptable in cases where the construction/alteration is temporary or a proposal is abandoned. This notification process is designed to permit the FAA the necessary time to change affected procedures and/or minimum flight altitudes, and to otherwise alert airmen of the structure's presence.

Note-
NOTIFICATION AS REQUIRED IN THE DETERMINATION IS CRITICAL TO AVIATION SAFETY.

5. MODIFICATIONS AND DEVIATIONS

a. Requests for modification or deviation from the standards outlined in this AC must be submitted to the FAA Regional Air Traffic Division office serving the area where the structure would be located. The sponsor is responsible for adhering to approved marking and/or lighting limitations, and/or recommendations given, and should notify the FAA and FCC (for those structures regulated by the FCC) prior to removal of marking and/or lighting. A request received after a determination is issued may require a new study and could result in a new determination.

b. ***Modifications***. Modifications will be based on whether or not they impact aviation safety. Examples of modifications that may be considered:

1. ***Marking and/or Lighting Only a Portion of an Object.*** The object may be so located with respect to other objects or terrain that only a portion of it needs to be marked or lighted.

2. ***No Marking and/or Lighting***. The object may be so located with respect to other objects or terrain, removed from the general flow of air traffic, or may be so conspicuous by its shape, size, or color that marking or lighting would serve no useful purpose.

3. ***Voluntary Marking and/or Lighting***. The object may be so located with respect to other objects or terrain that the sponsor feels increased conspicuity would better serve aviation safety. Sponsors who desire to voluntarily mark and/or light their structure should request the proper marking and/or lighting from the FAA to ensure no aviation safety issues are impacted.

4. ***Marking or Lighting an Object in Accordance with the Standards for an Object of Greater Height or Size.*** The object may present such an extraordinary hazard potential that higher standards may be recommended for increased conspicuity to ensure the safety to air navigation.

c. ***Deviations***. The FAA regional office conducts an aeronautical study of the proposed deviation(s) and forwards its recommendation to FAA headquarters in Washington, DC, for final approval. Examples of deviations that may be considered:

1. Colors of objects.
2. Dimensions of color bands or rectangles.
3. Colors/types of lights.
4. Basic signals and intensity of lighting.
5. Night/day lighting combinations.
6. Flash rate.

d. The FAA strongly recommends that sponsors become familiar with the different types of lighting systems and to specifically request the type of lighting system desired when submitting FAA Form 7460-1. (This request should be noted in "item 2.D" of the FAA form.) Information on these systems can be found in Chapter 12, Table 4 of this AC. While the FAA will make every effort to accommodate the request, sponsors should also request information from system manufacturers. In order to determine which system best meets their needs based on purpose, installation, and maintenance costs.

6. ADDITIONAL NOTIFICATION

Sponsors are reminded that any change to the submitted information on which the FAA has based its determination, including modification, deviation or optional upgrade to white lighting on structures which are regulated by the FCC, must also be filed with the FCC prior to making the change for proper authorization and annotations of obstruction marking and lighting. These structures will be subject to inspection and enforcement of marking and lighting requirements by the FCC. FCC Forms and Bulletins can be obtained from the FCC's National Call Center at 1-888-CALL-FCC (1-888-225-5322). Upon completion of the actual change, notify the Aeronautical Charting office at:

NOAA/NOS
Aeronautical Charting Division
Station 5601, N/ACC113
1305 East-West Highway
Silver Spring, MD 20910-3233

7. METRIC UNITS

To promote an orderly transition to metric units, sponsors should include both English and metric (SI units) dimensions. The metric conversions may not be exact equivalents, and until there is an official changeover to the metric system, the English dimensions will govern.

CHAPTER 2. GENERAL

20. STRUCTURES TO BE MARKED AND LIGHTED

Any temporary or permanent structure, including all appurtenances, that exceeds an overall height of 200 feet (61m) above ground level (AGL) or exceeds any obstruction standard contained in 14 CFR part 77, should normally be marked and/or lighted. However, an FAA aeronautical study may reveal that the absence of marking and/or lighting will not impair aviation safety. Conversely, the object may present such an extraordinary hazard potential that higher standards may be recommended for increased conspicuity to ensure safety to air navigation. Normally outside commercial lighting is not considered sufficient reason to omit recommended marking and/or lighting. Recommendations on marking and/or lighting structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design. The FAA may also recommend marking and/or lighting a structure that does not exceed 200 (61m) feet AGL or 14 CFR part 77 standards because of its particular location.

21. GUYED STRUCTURES

The guys of a 2,000-foot (610m) skeletal tower are anchored from 1,600 feet (488m) to 2,000 feet (610m) from the base of the structure. This places a portion of the guys 1,500 feet (458m) from the tower at a height of between 125 feet (38m) to 500 feet (153m) AGL. 14 CFR part 91, section 119, requires pilots, when operating over other than congested areas, to remain at least 500 feet (153m) from man-made structures. Therefore, the tower must be cleared by 2,000 feet (610m) horizontally to avoid all guy wires. Properly maintained marking and lighting are important for increased conspicuity since the guys of a structure are difficult to see until aircraft are dangerously close.

22. MARKING AND LIGHTING EQUIPMENT

Considerable effort and research have been expended in determining the minimum marking and lighting systems or quality of materials that will produce an acceptable level of safety to air navigation. The FAA will recommend the use of only those marking and lighting systems that meet established technical standards. While additional lights may be desirable to identify an obstruction to air navigation and may, on occasion be recommended, the FAA will recommend minimum standards in the interest of safety, economy, and related concerns. Therefore, to provide an adequate level of safety, obstruction lighting systems should be installed, operated, and maintained in accordance with the recommended standards herein.

23. LIGHT FAILURE NOTIFICATION

a. Sponsors should keep in mind that conspicuity is achieved only when all recommended lights are working. Partial equipment outages decrease the margin of safety. Any outage should be corrected as soon as possible. Failure of a steady burning side or intermediate light should be corrected as soon as possible, but notification is not required.

b. Any failure or malfunction that lasts more than thirty (30) minutes and affects a top light or flashing obstruction light, regardless of its position, should be reported immediately to the nearest flight service station (FSS) so a Notice to Airmen (NOTAM) can be issued. Toll-free numbers for FSS are listed in most telephone books or on the FAA's Website at www.faa.gov/ats/ata/ata400. This report should contain the following information:

1. Name of persons or organizations reporting light failures including any title, address, and telephone number.

2. The type of structure.

3. Location of structure (including latitude and longitude, if known, prominent structures, landmarks, etc.).

4. Height of structure above ground level (AGL)/above mean sea level (AMSL), if known.

5. A return to service date.

6. FCC Antenna Registration Number (for structures that are regulated by the FCC).

Note-
1. When the primary lamp in a double obstruction light fails, and the secondary lamp comes on, no report is required. However, when one of the lamps in an incandescent L-864 flashing red beacon fails, it should be reported.

2. After 15 days, the NOTAM is automatically deleted from the system. The sponsor is requested to call the nearest FSS to extend the outage date. In addition, the sponsor is required to report a return to service date.

24. NOTIFICATION OF RESTORATION

As soon as normal operation is restored, notify the same AFSS/FSS that received the notification of failure. The FCC advises that noncompliance with notification procedures could subject its sponsor to penalties or monetary forfeitures.

25. FCC REQUIREMENT

FCC licensees are required to file an environmental assessment with the Commission when seeking authorization for the use of the high intensity flashing white lighting system on structures located in residential neighborhoods, as defined by the applicable zoning law.

CHAPTER 3. MARKING GUIDLINES

30. PURPOSE

This chapter provides recommended guidelines to make certain structures conspicuous to pilots during daylight hours. One way of achieving this conspicuity is by painting and/or marking these structures. Recommendations on marking structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design.

31. PAINT COLORS

Alternate sections of aviation orange and white paint should be used as they provide maximum visibility of an obstruction by contrast in colors.

32. PAINT STANDARDS

The following standards should be followed. To be effective, the paint used should meet specific color requirements when freshly applied to a structure. Since, all outdoor paints deteriorate with time and it is not practical to give a maintenance schedule for all climates, surfaces should be repainted when the color changes noticeably or its effectiveness is reduced by scaling, oxidation, chipping, or layers of contamination.

a. ***Materials and Application***. Quality paint and materials should be selected to provide extra years of service. The paint should be compatible with the surfaces to be painted, including any previous coatings, and suitable for the environmental conditions. Surface preparation and paint application should be in accordance with manufacturer's recommendations.

Note-
In-Service Aviation Orange Color Tolerance Charts are available from private suppliers for determining when repainting is required. The color should be sampled on the upper half of the structure, since weathering is greater there.

b. ***Surfaces Not Requiring Paint***. Ladders, decks, and walkways of steel towers and similar structures need not be painted if a smooth surface presents a potential hazard to maintenance personnel. Paint may also be omitted from precision or critical surfaces if it would have an adverse effect on the transmission or radiation characteristics of a signal. However, the overall marking effect of the structure should not be reduced.

c. ***Skeletal Structures***. Complete all marking/painting prior to or immediately upon completion of construction. This applies to catenary support structures, radio and television towers, and similar skeletal structures. To be effective, paint should be applied to all inner and outer surfaces of the framework.

33. PAINT PATTERNS

Paint patterns of various types are used to mark structures. The pattern to be used is determined by the size and shape of the structure. The following patterns are recommended.

a. ***Solid Pattern***. Obstacles should be colored aviation orange if the structure has both horizontal and vertical dimensions not exceeding 10.5 feet (3.2m).

b. ***Checkerboard Pattern***. Alternating rectangles of aviation orange and white are normally displayed on the following structures:

1. Water, gas, and grain storage tanks.

2. Buildings, as required.

3. Large structures exceeding 10.5 feet (3.2m) across having a horizontal dimension that is equal to or greater than the vertical dimension.

c. ***Size of Patterns***. Sides of the checkerboard pattern should measure not less than 5 feet (1.5m) or more than 20 feet (6m) and should be as nearly square as possible. However, if it is impractical because of the size or shape of a structure, the patterns may have sides less than 5 feet (1.5m). When possible, corner surfaces should be colored orange.

d. ***Alternate Bands***. Alternate bands of aviation orange and white are normally displayed on the following structures:

1. Communication towers and catenary support structures.

2. Poles.

3. Smokestacks.

4. Skeletal framework of storage tanks and similar structures.

5. Structures which appear narrow from a side view, that are 10.5 feet (3.2m) or more across and the horizontal dimension is less than the vertical dimension.

6. Wind turbine generator support structures including the nacelle or generator housing.

7. Coaxial cable, conduits, and other cables attached to the face of a tower.

e. ***Color Band Characteristics***. Bands for structures of any height should be:

1. Equal in width, provided each band is not less than $1^1/_2$ feet (0.5m) or more than 100 feet (31m) wide.

2. Perpendicular to the vertical axis with the bands at the top and bottom ends colored orange.

3. An odd number of bands on the structure.

4. Approximately one-seventh the height if the structure is 700 feet (214m) AGL or less. For each additional 200 feet (61m) or fraction thereof, add one (1) additional orange and one (1) additional white band.

5. Equal and in proportion to the structure's height AGL.

Structure Height to Bandwidth Ratio

Example: If a Structure is:		
Greater Than	**But Not More Than**	**Band Width**
10.5 feet (3.2m)	700 feet (214m)	$^1/_7$ of height
701 feet (214m)	900 feet (275m)	$^1/_9$ of height
901 feet (275m)	1,100 feet (336m)	$^1/_{11}$ of height
1,100 feet (336m)	1,300 feet (397m)	$^1/_{13}$ of height

TBL 1

f. ***Structures With a Cover or Roof***. If the structure has a cover or roof, the highest orange band should be continued to cover the entire top of the structure.

g. ***Skeletal Structures Atop Buildings***. If a flagpole, skeletal structure, or similar object is erected on top of a building, the combined height of the object and building will determine whether marking is recommended; however, only the height of the object under study determines the width of the color bands.

h. ***Partial Marking***. If marking is recommended for only a portion of a structure because of shielding by other objects or terrain, the width of the bands should be determined by the overall height of the structure. A minimum of three bands should be displayed on the upper portion of the structure.

i. ***Teardrop Pattern***. Spherical water storage tanks with a single circular standpipe support may be marked in a teardrop-striped pattern. The tank should show alternate stripes of aviation orange and white. The stripes should extend from the top center of the tank to its supporting standpipe. The width of the stripes should be equal, and the width of each stripe at the greatest girth of the tank should not be less than 5 feet (1.5m) nor more than 15 feet (4.6m).

j. ***Community Names***. If it is desirable to paint the name of the community on the side of a tank, the stripe pattern may be broken to serve this purpose. This open area should have a maximum height of 3 feet (0.9m).

k. ***Exceptions***. Structural designs not conducive to standard markings may be marked as follows:

1. If it is not practical to color the roof of a structure in a checkerboard pattern, it may be colored solid orange.

2. If a spherical structure is not suitable for an exact checkerboard pattern, the shape of the rectangles may be modified to fit the shape of the surface.

3. Storage tanks not suitable for a checkerboard pattern may be colored by alternating bands of aviation orange and white or a limited checkerboard pattern applied to the upper one-third of the structure.

4. The skeletal framework of certain water, gas, and grain storage tanks may be excluded from the checkerboard pattern.

34. MARKERS

Markers are used to highlight structures when it is impractical to make them conspicuous by painting. Markers may also be used in addition to aviation orange and white paint when additional conspicuity is necessary for aviation safety. They should be displayed in conspicuous positions on or adjacent to the structures so as to retain the general definition of the structure. They should be recognizable in clear air from a distance of at least 4,000 feet (1219m) and in all directions from which aircraft are likely to approach. Markers should be distinctively shaped, i.e., spherical or cylindrical, so they are not mistaken for items that are used to convey other information. They should be replaced when faded or otherwise deteriorated.

a. *Spherical Markers*. Spherical markers are used to identify overhead wires. Markers may be of another shape, i.e., cylindrical, provided the projected area of such markers will not be less than that presented by a spherical marker.

1. *Size and Color*.

The diameter of the markers used on extensive catenary wires across canyons, lakes, rivers, etc., should be not less than 36 inches (91cm). Smaller 20-inch (51cm) spheres are permitted on less extensive power lines or on power lines below 50 feet (15m) above the ground and within 1,500 feet (458m) of an airport runway end. Each marker should be a solid color such as aviation orange, white, or yellow.

2. *Installations.*

(a) *Spacing.* Markers should be spaced equally along the wire at intervals of approximately 200 feet (61m) or a fraction thereof. Intervals between markers should be less in critical areas near runway ends (i.e., 30 to 50 feet (10m to 15m)). They should be displayed on the highest wire or by another means at the same height as the highest wire. Where there is more than one wire at the highest point, the markers may be installed alternately along each wire if the distance between adjacent markers meets the spacing standard. This method allows the weight and wind loading factors to be distributed.

(b) *Pattern*. An alternating color scheme provides the most conspicuity against all backgrounds. Mark overhead wires by alternating solid colored markers of aviation orange, white, and yellow. Normally, an orange sphere is placed at each end of a line and the spacing is adjusted (not to exceed 200 feet (61m)) to accommodate the rest of the markers. When less than four markers are used, they should all be aviation orange.

b. *Flag Markers*. Flags are used to mark certain structures or objects when it is technically impractical to use spherical markers or painting. Some examples are temporary construction equipment, cranes, derricks, oil and other drilling rigs. Catenaries should use spherical markers.

1. *Minimum Size*. Each side of the flag marker should be at least 2 feet (0.6m) in length.

2. *Color Patterns*. Flags should be colored as follows:

(a) *Solid*. Aviation orange.

(b) *Orange and White*. Arrange two triangular sections, one aviation orange and the other white to form a rectangle.

(c) *Checkerboard.* **Flags** 3 feet (0.9m) or larger should be a checkerboard pattern of aviation orange and white squares, each 1 foot (0.3m) plus or minus 10 percent.

3. *Shape*. Flags should be rectangular in shape and have stiffeners to keep them from drooping in calm wind.

4. *Display*. Flag markers should be displayed around, on top, or along the highest edge of the obstruction. When flags are used to mark extensive or closely grouped obstructions, they should be displayed approximately 50 feet (15m) apart. The flag stakes should be of such strength and height that they will support the flags above all surrounding ground, structures, and/or objects of natural growth.

35. UNUSUAL COMPLEXITIES

The FAA may also recommend appropriate marking in an area where obstructions are so grouped as to present a common obstruction to air navigation.

36. OMISSION OR ALTERNATIVES TO MARKING

There are two alternatives to marking. Either alternative requires FAA review and concurrence.

a. *High Intensity Flashing White Lighting Systems*. The high intensity lighting systems are more effective than aviation orange and white paint and therefore can be recommended instead of marking. This is particularly true under certain ambient light conditions involving the position of the sun relative to the direction of flight. When high intensity lighting systems are operated during daytime and twilight, other methods of marking may be omitted. When operated 24 hours a day, other methods of marking and lighting may be omitted.

b. *Medium Intensity Flashing White Lighting Systems.* When medium intensity lighting systems are operated during daytime and twilight on structures 500 feet (153m) AGL or less, other methods of marking may be omitted. When operated 24 hours a day on structures 500 feet (153m) AGL or less, other methods of marking and lighting may be omitted.

Note-
SPONSORS MUST ENSURE THAT ALTERNATIVES TO MARKING ARE COORDINATED WITH THE FCC FOR STRUCTURES UNDER ITS JURISDICTION PRIOR TO MAKING THE CHANGE.

CHAPTER 4. LIGHTING GUIDELINE

40. PURPOSE

This chapter describes the various obstruction lighting systems used to identify structures that an aeronautical study has determined will require added conspicuity. The lighting standards in this circular are the minimum necessary for aviation safety. Recommendations on lighting structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design.

41. STANDARDS

The standards outlined in this AC are based on the use of light units that meet specified intensities, beam patterns, color, and flash rates as specified in AC 150/5345-43.

These standards may be obtained from:

Department of Transportation
TASC
Subsequent Distribution Office, SVC-121.23
Ardmore East Business Center
3341 Q 75th Avenue
Landover, MD 20785

42. LIGHTING SYSTEMS

Obstruction lighting may be displayed on structures as follows:

a. ***Aviation Red Obstruction Lights***. Use flashing beacons and/or steady burning lights during nighttime.

b. ***Medium Intensity Flashing White Obstruction Lights.*** Medium intensity flashing white obstruction lights may be used during daytime and twilight with automatically selected reduced intensity for nighttime operation. When this system is used on structures 500 feet (153m) AGL or less in height, other methods of marking and lighting the structure may be omitted. Aviation orange and white paint is always required for daytime marking on structures exceeding 500 feet (153m) AGL. This system is not normally recommended on structures 200 feet (61m) AGL or less.

c. ***High Intensity Flashing White Obstruction Lights***. Use high intensity flashing white obstruction lights during daytime with automatically selected reduced intensities for twilight and nighttime operations. When this system is used, other methods of marking and lighting the structure may be omitted. This system should not be recommended on structures 500 feet (153m) AGL or less, unless an FAA aeronautical study shows otherwise.

Note-
All flashing lights on a structure should flash simultaneously except for catenary support structures, which have a distinct sequence flashing between levels.

d. ***Dual Lighting***. This system consists of red lights for nighttime and high or medium intensity flashing white lights for daytime and twilight. When a dual lighting system incorporates medium flashing intensity lights on structures 500 feet (153m) or less, or high intensity flashing white lights on structures of any height, other methods of marking the structure may be omitted.

e. ***Obstruction Lights During Construction***. As the height of the structure exceeds each level at which permanent obstruction lights would be recommended, two or more lights of the type specified in the determination should be installed at that level. Temporary high or medium intensity flashing white lights, as recommended in the determination, should be operated 24 hours a day until all permanent lights are in operation. In either case, two or more lights should be installed on the uppermost part of the structure any time it exceeds the height of the temporary construction equipment. They may be turned off for periods when they would interfere with construction personnel. If practical, permanent obstruction lights should be installed and operated at each level as construction progresses. The lights should be positioned to ensure that a pilot has an unobstructed view of at least one light at each level.

f. ***Obstruction Lights in Urban Areas***. When a structure is located in an urban area where there are numerous other white lights (e.g., streetlights, etc.) red obstruction lights with painting or a medium intensity dual system is recommended. Medium intensity lighting is not normally recommended on structures less than 200 feet (61m).

g. ***Temporary Construction Equipment Lighting***. Since there is such a variance in construction cranes, derricks, oil and other drilling rigs, each case should be considered individually. Lights should be installed according to the standards given in Chapters 5, 6, 7, or 8, as they would apply to permanent structures.

43. CATENARY LIGHTING

Lighted markers are available for increased night conspicuity of high-voltage (69KV or greater) transmission line catenary wires. These markers should be used on transmission line catenary wires near airports, heliports, across rivers, canyons, lakes, etc. The lighted markers should be manufacturer certified as recognizable from a minimum distance of 4,000 feet (1219m) under nighttime conditions, minimum visual flight rules (VFR) conditions or having a minimum intensity of at least 32.5 candela. The lighting unit should emit a steady burning red light. They should be used on the highest energized line. If the lighted markers are installed on a line other than the highest catenary, then markers specified in paragraph 34 should be used in addition to the lighted markers. (The maximum distance between the line energizing the lighted markers and the highest catenary above the lighted marker should be no more than 20 feet (6m).) Markers should be distinctively shaped, i.e., spherical, cylindrical, so they are not mistaken for items that are used to convey other information. They should be visible in all directions from which aircraft are likely to approach. The area in the immediate vicinity of the supporting structure's base should be clear of all items and/or objects of natural growth that could interfere with the line-of-sight between a pilot and the structure's lights. Where a catenary wire crossing requires three or more supporting structures, the inner structures should be equipped with enough light units per level to provide a full coverage.

44. INSPECTION, REPAIR AND MAINTENANCE

To ensure the proper candela output for fixtures with incandescent lamps, the voltage provided to the lamp filament should not vary more than plus or minus 3 percent of the rated voltage of the lamp. The input voltage should be measured at the lamp socket with the lamp operating during the hours of normal operation. (For strobes, the input voltage of the power supplies should be within 10 percent of rated voltage.) Lamps should be replaced after being operated for not more than 75 percent of their rated life or immediately upon failure. Flashtubes in a light unit should be replaced immediately upon failure, when the peak effective intensity falls below specification limits or when the fixture begins skipping flashes, or at the manufacturer's recommended intervals. Due to the effects of harsh environments, beacon lenses should be visually inspected for ultraviolet damage, cracks, crazing, dirt build up, etc., to insure that the certified light output has not deteriorated. (See paragraph 23, for reporting requirements in case of failure.)

45. NONSTANDARD LIGHTS

Moored balloons, chimneys, church steeples, and similar obstructions may be floodlighted by fixed search light projectors installed at three or more equidistant points around the base of each obstruction. The searchlight projectors should provide an average illumination of at least 15 foot-candles over the top one-third of the obstruction.

46. PLACEMENT FACTORS

The height of the structure AGL determines the number of light levels. The light levels may be adjusted slightly, but not to exceed 10 feet (3m), when necessary to accommodate guy wires and personnel who replace or repair light fixtures. Except for catenary support structures, the following factors should be considered when determining the placement of obstruction lights on a structure.

a. ***Red Obstruction Lighting Systems***. The overall height of the structure including all appurtenances such as rods, antennas, obstruction lights, etc., determines the number of light levels.

b. ***Medium Intensity Flashing White Obstruction Lighting Systems***. The overall height of the structure including all appurtenances such as rods, antennas, obstruction lights, etc., determines the number of light levels.

c. ***High Intensity Flashing White Obstruction Lighting Systems***. The overall height of the main structure including all appurtenances such as rods, antennas, obstruction lights, etc., determines the number of light levels.

d. ***Dual Obstruction Lighting Systems***. The overall height of the structure including all appurtenances such as rods, antennas, obstruction lights, etc., is used to determine the number of light levels for a medium intensity white obstruction light/red obstruction dual lighting system. The overall height of the structure including all appurtenances is used to determine the number of light levels for a high intensity white obstruction light/red obstruction dual lighting system.

e. ***Adjacent Structures***. The elevation of the tops of adjacent buildings in congested areas may be used as the equivalent of ground level to determine the proper number of light levels required.

f. ***Shielded Lights***. If an adjacent object shields any light, horizontal placement of the lights should be adjusted or additional lights should be mounted on that object to retain or contribute to the definition of the obstruction.

47. MONITORING OBSTRUCTION LIGHTS

Obstruction lighting systems should be closely monitored by visual or automatic means. It is extremely important to visually inspect obstruction lighting in all operating intensities at least once every 24 hours on systems without automatic monitoring. In the event a structure is not readily accessible for visual observation, a properly maintained automatic monitor should be used. This monitor should be designed to register the malfunction of any light on the obstruction regardless of its position or color. When using remote monitoring devices, the communication status and operational status of the system should be confirmed at least once every 24 hours. The monitor (aural or visual) should be located in an area generally occupied by responsible personnel. In some cases, this may require a remote monitor in an attended location. For each structure, a log should be maintained in which daily operations status of the lighting system is recorded. Beacon lenses should be replaced if serious cracks, crazing, dirt build up, etc., has occurred.

48. ICE SHIELDS

Where icing is likely to occur, metal grates or similar protective ice shields should be installed directly over each light unit to prevent falling ice or accumulations from damaging the light units.

49. DISTRACTION

a. Where obstruction lights may distract operators of vessels in the proximity of a navigable waterway, the sponsor must coordinate with the Commandant, U.S. Coast Guard, to avoid interference with marine navigation.

b. The address for marine information and coordination is:

Chief, Aids to Navigation
Division (OPN)
U.S. Coast Guard Headquarters
2100 2nd Street, SW., Rm. 3610
Washington, DC 20593-0001
Telephone: (202) 267-0980

CHAPTER 5. RED OBSTRUCTION LIGHT SYSTEM

50. PURPOSE

Red Obstruction lights are used to increase conspicuity during nighttime. Daytime and twilight marking is required. Recommendations on lighting structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design.

51. STANDARDS

The red obstruction lighting system is composed of flashing omnidirectional beacons (L-864) and/or steady burning (L-810) lights. When one or more levels is comprised of flashing beacon lighting, the lights should flash simultaneously.

a. ***Single Obstruction Light***. A single (L-810) light may be used when more than one obstruction light is required either vertically or horizontally or where maintenance can be accomplished within a reasonable time.

1. ***Top Level***. A single light may be used to identify low structures such as airport ILS buildings and long horizontal structures such as perimeter fences and building roof outlines.

2. ***Intermediate Level***. Single lights may be used on skeletal and solid structures when more than one level of lights is installed and there are two or more single lights per level.

b. ***Double Obstruction Light***. A double (L-810) light should be installed when used as a top light, at each end of a row of single obstruction lights, and in areas or locations where the failure of a single unit could cause an obstruction to be totally unlighted.

1. ***Top Level.*** **Structures** 150 feet (46m) AGL or less should have one or more double lights installed at the highest point and operating simultaneously.

2. ***Intermediate Level***. Double lights should be installed at intermediate levels when a malfunction of a single light could create an unsafe condition and in remote areas where maintenance cannot be performed within a reasonable time. Both units may operate simultaneously, or a transfer relay may be used to switch to a spare unit should the active system fail.

3. ***Lowest Level***. The lowest level of light units may be installed at a higher elevation than normal on a structure if the surrounding terrain, trees, or adjacent building(s) would obscure the lights. In certain instances, as determined by an FAA aeronautical study, the lowest level of lights may be eliminated.

52. CONTROL DEVICE

Red obstruction lights should be operated by a satisfactory control device (e.g., photo cell, timer, etc.) adjusted so the lights will be turned on when the northern sky illuminance reaching a vertical surface falls below a level of 60 foot-candles (645.8 lux) but before reaching a level of 35 foot-candles (367.7 lux). The control device should turn the lights off when the northern sky illuminance rises to a level of not more than 60 foot-candles (645.8 lux). The lights may also remain on continuously. The sensing device should, if practical, face the northern sky in the Northern Hemisphere. (See AC 150/5345-43.)

53. POLES, TOWERS, AND SIMILAR SKELETAL STRUCTURES

The following standards apply to radio and television towers, supporting structures for overhead transmission lines, and similar structures.

a. ***Top Mounted Obstruction Light.***

1. ***Structures 150 Feet (46m) AGL or Less***. Two or more steady burning (L-810) lights should be installed in a manner to ensure an unobstructed view of one or more lights by a pilot.

2. ***Structures Exceeding 150 Feet (46m) AGL***. At least one red flashing (L-864) beacon should be installed in a manner to ensure an unobstructed view of one or more lights by a pilot.

3. ***Appurtenances 40 Feet (12m) or Less***. If a rod, antenna, or other appurtenance 40 feet (12m) or less in height is incapable of supporting a red flashing beacon, then it may be placed at the base of the appurtenance. If the mounting location does not allow unobstructed viewing of the beacon by a pilot, then additional beacons should be added.

4. ***Appurtenances Exceeding 40 Feet (12m)***. If a rod, antenna, or other appurtenance exceeding 40 feet (12m) in height is incapable of supporting a red flashing beacon, a supporting mast with one or more beacons should be installed adjacent to the appurtenance. Adjacent installations should not exceed the height of the appurtenance and be within 40 feet (12m) of the tip to allow the pilot an unobstructed view of at least one beacon.

b. ***Mounting Intermediate Levels***. The number of light levels is determined by the height of the structure, including all appurtenances, and is detailed in Appendix 1. The number of lights on each level is determined by the shape and height of the structure. These lights should be mounted so as to ensure an unobstructed view of at least one light by a pilot.

1. ***Steady Burning Lights (L-810).***

(a) ***Structures 350 Feet (107m) AGL or Less.*** Two or more steady burning (L-810) lights should be installed on diagonally or diametrically opposite positions.

(b) ***Structures Exceeding 350 Feet (107m) AGL.*** Install steady burning (L-810) lights on each outside corner of each level.

2. ***Flashing Beacons (L-864).***

(a) ***Structures 350 Feet (107m) AGL or Less.*** These structures do not require flashing (L-864) beacons at intermediate levels.

(b) ***Structure Exceeding 350 Feet (107m) AGL.*** At intermediate levels, two beacons (L-864) should be mounted outside at diagonally opposite positions of intermediate levels.

54. CHIMNEYS, FLARE STACKS, AND SIMILAR SOLID STRUCTURES

a. *Number of Light Units.*

1. The number of units recommended depends on the diameter of the structure at the top. The number of lights recommended below are the minimum.

2. When the structure diameter is:

(a) *20 Feet (6m) or Less.* Three light units per level.

(b) *Exceeding 20 Feet (6m) But Not More Than 100 Feet (31m).* Four light units per level.

(c) *Exceeding 100 Feet (31m) But Not More Than 200 Feet (61m).* Six light units per level.

(d) *Exceeding 200 Feet (61m).* Eight light units per level.

b. ***Top Mounted Obstruction Lights.***

1. *Structures 150 Feet (46m) AGL or Less.* L-810 lights should be installed horizontally at regular intervals at or near the top.

2. *Structures Exceeding 150 Feet (46m) AGL.* At least three L-864 beacons should be installed.

3. *Chimneys, Cooling Towers, and Flare Stacks.* Lights may be displayed as low as 20 feet (6m) below the top to avoid the obscuring effect of deposits and heat generally emitted by this type of structure. It is important that these lights be readily accessible for cleaning and lamp replacement. It is understood that with flare stacks, as well as any other structures associated with the petrol-chemical industry, normal lighting requirements may not be necessary. This could be due to the location of the flare stack/structure within a large well-lighted petrol-chemical plant or the fact that the flare, or working lights surrounding the flare stack/structure, is as conspicuous as obstruction lights.

c. ***Mounting Intermediate Levels.*** The number of light levels is determined by the height of the structure including all appurtenances. For cooling towers 600 feet (183m) or less, intermediate light levels are not necessary. Structures exceeding 600 feet (183m) AGL should have a second level of light units installed approximately at the midpoint of the structure and in a vertical line with the top level of lights.

1. ***Steady Burning (L-810) Lights.*** The recommended number of light levels may be obtained from Appendix 1. At least three lights should be installed on each level.

2. ***Flashing (L-864) Beacons.*** The recommended number of beacon levels may be obtained from Appendix 1. At least three lights should be installed on each level.

(a) *Structures 350 Feet (107m) AGL or Less.* These structures do not need intermediate levels of flashing beacons.

(b) *Structures Exceeding 350 Feet (107m) AGL.* At least three flashing (L-864) beacons should be installed on each level in a manner to allow an unobstructed view of at least one beacon.

55. WIND TURBINE STRUCTURES

Wind turbine structures should be lighted by mounting two flashing red beacons (L-864) on top of the generator housing. Both beacons should flash simultaneously. Lighting fixtures are to be mounted at a horizontal separation to ensure an unobstructed view of at least one fixture by a pilot approaching from **any** direction.

56. GROUP OF OBSTRUCTIONS

When individual objects, except wind turbines, within a group of obstructions are not the same height and are spaced a maximum of 150 feet (46m) apart, the prominent objects within the group should be lighted in accordance with the standards for individual obstructions of a corresponding height. If the outer structure is shorter than the prominent, the outer structure should be lighted in accordance with the standards for individual obstructions of a corresponding height. Light units should be placed to ensure that the light is visible to a pilot approaching from **any** direction. In addition, at least one flashing beacon should be installed at the top of a prominent center obstruction or on a special tower located near the center of the group.

57. ALTERNATE METHOD OF DISPLAYING OBSTRUCTION LIGHTS

When recommended in an FAA aeronautical study, lights may be placed on poles equal to the height of the obstruction and installed on or adjacent to the structure instead of installing lights on the obstruction.

58. PROMINENT BUILDINGS, BRIDGES, AND SIMILAR EXTENSIVE OBSTRUCTIONS

When objects within a group of obstructions are approximately the same overall height above the surface and are located a maximum of 150 feet (46m) apart, the group of obstructions may be considered an extensive obstruction. Install light units on the same horizontal plane at the highest portion or edge of prominent obstructions. Light units should be placed to ensure that the light is visible to a pilot approaching from **any** direction. If the structure is a bridge and is over navigable water, the sponsor must obtain prior approval of the lighting installation from the Commander of the District Office of the United States Coast Guard to avoid interference with marine navigation. Steady burning lights should be displayed to indicate the extent of the obstruction as follows:

a. ***Structures 150 Feet (46m) or Less in Any Horizontal Direction***. If the structure/bridge/extensive obstruction is 150 feet (46m) or less horizontally, at least one steady burning light (L-810) should be displayed on the highest point at each end of the major axis of the obstruction. If this is impractical because of the overall shape, display a double obstruction light in the center of the highest point.

b. ***Structures Exceeding 150 Feet (46m) in at Least One Horizontal Direction***. If the structure/bridge/extensive obstruction exceeds 150 feet (46m) horizontally, display at least one steady burning light for each 150 feet (46m), or fraction thereof, of the overall length of the major axis. At least one of these lights should be displayed on the highest point at each end of the obstruction. Additional lights should be displayed at approximately equal intervals not to exceed 150 feet (46m) on the highest points along the edge between the end lights. If an obstruction is located near a landing area and two or more edges are the same height, the edge nearest the landing area should be lighted.

c. ***Structures Exceeding 150 Feet (46m) AGL***. Steady burning red obstruction lights should be installed on the highest point at each end. At intermediate levels, steady burning red lights should be displayed for each 150 feet (46m) or fraction thereof. The vertical position of these lights should be equidistant between the top lights and the ground level as the shape and type of obstruction will permit. One such light should be displayed at each outside corner on each level with the remaining lights evenly spaced between the corner lights.

d. ***Exceptions***. Flashing red beacons (L-864) may be used instead of steady burning obstruction lights if early or special warning is necessary. These beacons should be displayed on the highest points of an extensive obstruction at intervals not exceeding 3,000 feet (915m). At least three beacons should be displayed on one side of the extensive obstruction to indicate a line of lights.

e. ***Ice Shields***. Where icing is likely to occur, metal grates or similar protective ice shields should be installed directly over each light unit to prevent falling ice or accumulations from damaging the light units. The light should be mounted in a manner to ensure an unobstructed view of at least one light by a pilot approaching from any direction.

CHAPTER 6. MEDIUM INTENSITY FLASHING WHITE OBSTRUCTION LIGHT SYSTEMS

60. PURPOSE

Medium intensity flashing white (L-865) obstruction lights may provide conspicuity both day and night. Recommendations on lighting structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design.

61. STANDARDS

The medium intensity flashing white light system is normally composed of flashing omnidirectional lights. Medium intensity flashing white obstruction lights may be used during daytime and twilight with automatically selected reduced intensity for nighttime operation. When this system is used on structures 500 feet (153m) AGL or less in height, other methods of marking and lighting the structure may be omitted. Aviation orange and white paint is always required for daytime marking on structures exceeding 500 feet (153m) AGL. This system is not normally recommended on structures 200 feet (61m) AGL or less.

The use of a 24-hour medium intensity flashing white light system in urban/populated areas in not normally recommended due to their tendency to merge with background lighting in these areas at night. This makes it extremely difficult for some types of aviation operations, i.e., med-evac, and police helicopters to see these structures. The use of this type of system in urban and rural areas often results in complaints. In addition, this system is not recommended on structures within 3 nautical miles of an airport.

62. RADIO AND TELEVISION TOWERS AND SIMILAR SKELETAL STRUCTURES

a. *Mounting Lights*. The number of levels recommended depends on the height of the structure, including antennas and similar appurtenances.

1. *Top Levels*. One or more lights should be installed at the highest point to provide 360-degree coverage ensuring an unobstructed view.

2. *Appurtenances 40 feet (12m) or less*. If a rod, antenna, or other appurtenance 40 feet (12m) or less in height is incapable of supporting the medium intensity flashing white light, then it may be placed at the base of the appurtenance. If the mounting location does not allow unobstructed viewing of the medium intensity flashing white light by a pilot, then additional lights should be added.

3. *Appurtenances Exceeding 40 feet (12m)*. If a rod, antenna, or other appurtenance exceeds 40 feet (12m) above the tip of the main structure, a medium intensity flashing white light should be placed within 40 feet (12m) from the top of the appurtenance. If the appurtenance (such as a whip antenna) is incapable of supporting the light, one or more lights should be mounted on a pole adjacent to the appurtenance. Adjacent installations should not exceed the height of the appurtenance and be within 40 feet (12m) of the tip to allow the pilot an unobstructed view of at least one light.

b. *Intermediate Levels*. At intermediate levels, two beacons (L-865) should be mounted outside at diagonally or diametrically opposite positions of intermediate levels. The lowest light level should not be less than 200 feet (61m) AGL.

c. *Lowest Levels*. The lowest level of light units may be installed at a higher elevation than normal on a structure if the surrounding terrain, trees, or adjacent building(s) would obscure the lights. In certain instances, as determined by an FAA aeronautical study, the lowest level of lights may be eliminated.

d. *Structures 500 Feet (153m) AGL or Less*. When white lights are used during nighttime and twilight only, marking is required for daytime. When operated 24 hours a day, other methods of marking and lighting are not required.

e. *Structures Exceeding 500 Feet (153m) AGL*. The lights should be used during nighttime and twilight and may be used 24 hours a day. Marking is always required for daytime.

f. *Ice Shields*. Where icing is likely to occur, metal grates or similar protective ice shields should be installed directly over each light unit to prevent falling ice or accumulations from damaging the light units. The light should be mounted in a manner to ensure an unobstructed view of at least one light by a pilot approaching from any direction.

63. CONTROL DEVICE

The light intensity is controlled by a device that changes the intensity when the ambient light changes. The system should automatically change intensity steps when the northern sky illumination in the Northern Hemisphere on a vertical surface is as follows:

a. *Twilight-to-Night*. This should not occur before the illumination drops below five foot-candles (53.8

lux) but should occur before it drops below two foot-candles (21.5 lux).

b. *Night-to-Day*. The intensity changes listed in subparagraph 63a above should be reversed when changing from the night to day mode.

64. CHIMNEYS, FLARE STACKS, AND SIMILAR SOLID STRUCTURES

a. ***Number of Light Units***. The number of units recommended depends on the diameter of the structure at the top. Normally, the top level is on the highest point of a structure. However, the top level of chimney lights may be installed as low as 20 feet (6m) below the top to minimize deposit build-up due to emissions. The number of lights recommended are the minimum. When the structure diameter is:

1. *20 Feet (6m) or Less*. Three light units per level.
2. *Exceeding 20 Feet (6m) But Not More Than 100 Feet (31m)*. Four light units per level.
3. *Exceeding 100 Feet (31m) But Not More Than 200 Feet (61m)*. Six light units per level.
4. *Exceeding 200 Feet (61m)*. Eight light units per level.

65. WIND TURBINE STRUCTURES

Wind turbine structures should be lighted by mounting two flashing white beacons (L-865) on top of the generator housing. Both beacons should flash simultaneously. Lighting fixtures are to be mounted at a horizontal separation to ensure an unobstructed view of at least one fixture by a pilot approaching from any direction. Intermediate light levels and other marking may be omitted on these structures.

66. GROUP OF OBSTRUCTIONS

When individual objects within a group of obstructions are not the same height and are spaced a maximum of 150 feet (46m) apart, the prominent objects within the group should be lighted in accordance with the standards for individual obstructions of a corresponding height. If the outer structure is shorter than the prominent, the outer structure should be lighted in accordance with the standards for individual obstructions of a corresponding height. Light units should be placed to ensure that the light is visible to a pilot approaching from **any** direction. In addition, at least one medium intensity flashing white light should be installed at the top of a prominent center obstruction or on a special tower located near the center of the group.

67. SPECIAL CASES

Where lighting systems are installed on structures located near highways, waterways, airport approach areas, etc., caution should be exercised to ensure that the lights do not distract or otherwise cause a hazard to motorists, vessel operators, or pilots on an approach to an airport. In these cases, shielding may be necessary. This shielding should not derogate the intended purpose of the lighting system.

68. PROMINENT BUILDINGS AND SIMILAR EXTENSIVE OBSTRUCTIONS

When objects within a group of obstructions are approximately the same overall height above the surface and are located a maximum of 150 feet (46m) apart, the group of obstructions may be considered an extensive obstruction. Install light units on the same horizontal plane at the highest portion or edge of prominent obstructions. Light units should be placed to ensure that the light is visible to a pilot approaching from **any** direction. Lights should be displayed to indicate the extent of the obstruction as follows:

a. ***Structures 150 Feet (46m) or Less in Any Horizontal Direction.*** If the structure/extensive obstruction is 150 feet (46m) or less horizontally, at least one light should be displayed on the highest point at each end of the major axis of the obstruction. If this is impractical because of the overall shape, display a double obstruction light in the center of the highest point.

b. ***Structures Exceeding 150 Feet (46m) in at Least One Horizontal Direction***. If the structure/extensive obstruction exceeds 150 feet (46m) horizontally, display at least one light for each 150 feet (46m) or fraction thereof, of the overall length of the major axis. At least one of these lights should be displayed on the highest point at each end of the obstruction. Additional lights should be displayed at approximately equal intervals not to exceed 150 feet (46m) on the highest points along the edge between the end lights. If an obstruction is located near a landing area and two or more edges are the same height, the edge nearest the landing area should be lighted.

c. ***Structures Exceeding 150 Feet (46m) AGL.*** Lights should be installed on the highest point at each end. At intermediate levels, lights should be displayed for each 150 feet (46m), or fraction thereof. The vertical position of these lights should be equidistant between the top lights and the ground level as the shape and type of obstruction will permit. One such light should be displayed at each outside corner on each level with the remaining lights evenly spaced between the corner lights.

CHAPTER 7. HIGH INTENSITY FLASHING WHITE OBSTRUCTION LIGHT SYSTEMS

70. PURPOSE

Lighting with high intensity (L-856) flashing white obstruction lights provides the highest degree of conspicuity both day and night. Recommendations on lighting structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design.

71. STANDARDS

Use high intensity flashing white obstruction lights during daytime with automatically selected reduced intensities for twilight and nighttime operations. When high intensity white lights are operated 24 hours a day, other methods of marking and lighting may be omitted. This system should not be recommended on structures 500 feet (153m) AGL or less unless an FAA aeronautical study shows otherwise.

72. CONTROL DEVICE

Light intensity is controlled by a device that changes the intensity when the ambient light changes. The use of a 24-hour high intensity flashing white light system in urban/populated areas is not normally recommended due to their tendency to merge with background lighting in these areas at night. This makes it extremely difficult for some types of aviation operations, i.e., med-evac, and police helicopters to see these structures. The use of this type of system in urban and rural areas often results in complaints.

The system should automatically change intensity steps when the northern sky illumination in the Northern Hemisphere on a vertical surface is as follows:

a. ***Day-to-Twilight***. This should not occur before the illumination drops to 60 foot-candles (645.8 lux), but should occur before it drops below 35 foot-candles (376.7 lux). The illuminance-sensing device should, if practical, face the northern sky in the Northern Hemisphere.

b. ***Twilight-to-Night***. This should not occur before the illumination drops below five foot-candles (53.8 lux), but should occur before it drops below two foot-candles (21.5 lux).

c. ***Night-to-Day***. The intensity changes listed in subparagraph 72 a and b above should be reversed when changing from the night to day mode.

73. UNITS PER LEVEL

One or more light units is needed to obtain the desired horizontal coverage. The number of light units recommended per level (except for the supporting structures of catenary wires and buildings) depends upon the average outside diameter of the specific structure, and the horizontal beam width of the light fixture. The light units should be installed in a manner to ensure an unobstructed view of the system by a pilot approaching from any direction. The number of lights recommended are the minimum. When the structure diameter is:

a. *20 Feet (6m) or Less.* Three light units per level.

b. *Exceeding 20 Feet (6m) But Not More Than 100 Feet (31m).* Four light units per level.

c. *Exceeding 100 Feet (31m).* Six light units per level.

74. INSTALLATION GUIDANCE

Manufacturing specifications provide for the effective peak intensity of the light beam to be adjustable from zero to 8 degrees above the horizon. Normal installation should place the top light at zero degrees to the horizontal and all other light units installed in accordance with Table 2:

Light Unit Elevation Above the Horizontal

Height of Light Unit Above Terrain	Degrees of Elevation Above the Horizontal
Exceeding 500 feet AGL	0
401 feet to 500 feet AGL	1
301 feet to 400 feet AGL	2
300 feet AGL or less	3

TBL 2

a. ***Vertical Aiming***. Where terrain, nearby residential areas, or other situations dictate, the light beam may be further elevated above the horizontal. The main beam of light at the lowest level should not strike the ground closer than 3 statute miles (5km) from the structure. If additional adjustments are necessary, the lights may be individually adjusted upward, in 1-degree increments, starting at the bottom. Excessive elevation may reduce its conspicuity by raising the beam above a collision course flight path.

b. ***Special Cases***. Where lighting systems are installed on structures located near highways, waterways, airport approach areas, etc., caution should be exercised to ensure that the lights do not distract or otherwise cause a hazard to motorists, vessel operators, or pilots on an approach to an airport. In these cases, shielding or an adjustment to the vertical or horizontal light aiming may be necessary. This adjustment should not derogate the intended purpose of the lighting system. Such adjustments may require review action as described in Chapter 1, paragraph 5.

c. ***Relocation or Omission of Light Units***. Light units should not be installed in such a manner that the light pattern/output is disrupted by the structure.

1. ***Lowest Level***. The lowest level of light units may be installed at a higher elevation than normal on a structure if the surrounding terrain, trees, or adjacent building(s) would obscure the lights. In certain instances, as determined by an FAA aeronautical study, the lowest level of lights may be eliminated.

2. ***Two Adjacent Structures***. Where two structures are situated within 500 feet (153m) of each other and the light units are installed at the same levels, the sides of the structures facing each other need not be lighted. However, all lights on both structures must flash simultaneously, except for adjacent catenary support structures. Adjust vertical placement of the lights to either or both structures' intermediate levels to place the lights on the same horizontal plane. Where one structure is higher than the other, complete level(s) of lights should be installed on that part of the higher structure that extends above the top of the lower structure. If the structures are of such heights that the levels of lights cannot be placed in identical horizontal planes, then the light units should be placed such that the center of the horizontal beam patterns do not face toward the adjacent structure. For example, structures situated north and south of each other should have the light units on both structures installed on a northwest/southeast and northeast/southwest orientation.

3. ***Three or More Adjacent Structures***. The treatment of a cluster of structures as an individual or a complex of structures will be determined by the FAA as the result of an aeronautical study, taking into consideration the location, heights, and spacing with other structures.

75. ANTENNA OR SIMILAR APPURTENANCE LIGHT

When a structure lighted by a high intensity flashing light system is topped with an antenna or similar appurtenance exceeding 40 feet (12m) in height, a medium intensity flashing white light (L-865) should be placed within 40 feet (12m) from the tip of the appurtenance. This light should operate 24 hours a day and flash simultaneously with the rest of the lighting system.

76. CHIMNEYS, FLARE STACKS, AND SIMILAR SOLID STRUCTURES

The number of light levels depends on the height of the structure excluding appurtenances. Three or more lights should be installed on each level in such a manner to ensure an unobstructed view by the pilot. Normally, the top level is on the highest point of a structure. However, the top level of chimney lights may be installed as low as 20 feet (6m) below the top to minimize deposit build-up due to emissions.

77. RADIO AND TELEVISION TOWERS AND SIMILAR SKELETAL STRUCTURES

a. *Mounting Lights*. The number of levels recommended depends on the height of the structure, excluding antennas and similar appurtenances. At least three lights should be installed on each level and mounted to ensure that the effective intensity of the full horizontal beam coverage is not impaired by the structural members.

b. *Top Level*. One level of lights should be installed at the highest point of the structure. If the highest point is a rod or antenna incapable of supporting a lighting system, then the top level of lights should be installed at the highest portion of the main skeletal structure. When guy wires come together at the top, it may be necessary to install this level of lights as low as 10 feet (3m) below the top. If the rod or antenna exceeds 40 feet (12m) above the main structure, a medium intensity flashing white light (L-865) should be mounted on the highest point. If the appurtenance (such as a whip antenna) is incapable of supporting a medium intensity light, one or more lights should be installed on a pole adjacent to the appurtenance. Adjacent installation should not exceed the height of the appurtenance and be within 40 feet (12m) of the top to allow an unobstructed view of at least one light.

c. *Ice Shields*. Where icing is likely to occur, metal grates or similar protective ice shields should be installed directly over each light unit to prevent falling ice or accumulations from damaging the light units.

78. HYPERBOLIC COOLING TOWERS

Light units should be installed in a manner to ensure an unobstructed view of at least two lights by a pilot approaching from **any** direction.

a. *Number of Light Units*. The number of units recommended depends on the diameter of the structure at the top. The number of lights recommended in the following table are the minimum. When the structure diameter is:

1. *20 Feet (6m) or Less.* Three light units per level.

2. *Exceeding 20 Feet (6m) But Not More Than 100 Feet (31m).* Four light units per level.

3. *Exceeding 100 Feet (31m) But Not More Than 200 Feet (61m).* Six light units per level.

4. *Exceeding 200 Feet (61m).* Eight light units per level.

b. ***Structures Exceeding 600 Feet (183m) AGL.*** Structures exceeding 600 feet (183m) AGL should have a second level of light units installed approximately at the midpoint of the structure and in a vertical line with the top level of lights.

79. PROMINENT BUILDINGS AND SIMILAR EXTENSIVE OBSTRUCTIONS

When objects within a group of obstructions are approximately the same overall height above the surface and are located not more than 150 feet (46m) apart, the group of obstructions may be considered an extensive obstruction. Install light units on the same horizontal plane at the highest portion or edge of prominent obstructions. Light units should be placed to ensure that the light is visible to a pilot approaching from **any** direction. These lights may require shielding, such as louvers, to ensure minimum adverse impact on local communities. Extreme caution in the use of high intensity flashing white lights should be exercised.

a. ***If the Obstruction is 200 feet (61m) or Less in Either Horizontal** Dimension,* install three or more light units at the highest portion of the structure in a manner to ensure that at least one light is visible to a pilot approaching from **any** direction. Units may be mounted on a single pedestal at or near the center of the obstruction. If light units are placed more than 10 feet (3m) from the center point of the structure, use a minimum of four units.

b. ***If the Obstruction Exceeds 200 Feet (61m) in One Horizontal Dimension,*** but is 200 feet (61m) or less in the other, two light units should be placed on each of the shorter sides. These light units may either be installed adjacent to each other at the midpoint of the edge of the obstruction or at (near) each corner with the light unit aimed to provide 180 degrees of coverage at each edge. One or more light units should be installed along the overall length of the major axis. These lights should be installed at approximately equal intervals not to exceed a distance of 100 feet (31m) from the corners or from each other.

c. ***If the Obstruction Exceeds 200 Feet (61m) in Both Horizontal Dimensions,*** light units should be equally spaced along the overall perimeter of the obstruction at intervals of 100 feet (31m) or fraction thereof.

CHAPTER 8. DUAL LIGHTING WITH RED/MEDIUM INTENSITY FLASHING WHITE SYSTEMS

80. PURPOSE

This dual lighting system includes red lights (L-864) for nighttime and medium intensity flashing white lights (L-865) for daytime and twilight use. This lighting system may be used in lieu of operating a medium intensity flashing white lighting system at night. There may be some populated areas where the use of medium intensity at night may cause significant environmental concerns. The use of the dual lighting system should reduce/mitigate those concerns. Recommendations on lighting structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design.

81. INSTALLATION

The light units should be installed as specified in the appropriate portions of Chapters 4, 5, and 6. The number of light levels needed may be obtained from Appendix 1.

82. OPERATION

Lighting systems should be operated as specified in Chapter 3. Both systems should not be operated at the same time; however, there should be no more than a 2-second delay when changing from one system to the other. Outage of one of two lamps in the uppermost red beacon (L-864 incandescent unit) or outage of any uppermost red light shall cause the white obstruction light system to operate in its specified "night" step intensity.

83. CONTROL DEVICE

The light system is controlled by a device that changes the system when the ambient light changes. The system should automatically change steps when the northern sky illumination in the Northern Hemisphere on a vertical surface is as follows:

a. ***Twilight-to-Night***. This should not occur before the illumination drops below 5 foot-candles (53.8 lux) but should occur before it drops below 2 foot-candles (21.5 lux).

b. ***Night-to-Day***. The intensity changes listed in subparagraph 83 a above should be reversed when changing from the night to day mode.

84. ANTENNA OR SIMILAR APPURTENANCE LIGHT

When a structure utilizing this dual lighting system is topped with an antenna or similar appurtenance exceeding 40 feet (12m) in height, a medium intensity flashing white (L-865) and a red flashing beacon (L-864) should be placed within 40 feet (12m) from the tip of the appurtenance. The white light should operate during daytime and twilight and the red light during nighttime. These lights should flash simultaneously with the rest of the lighting system.

85. WIND TURBINE STRUCTURES

Wind turbine structures should be lighted by mounting two flashing dual beacons (L-864/L-865) on top of the generator housing. Both beacons should flash simultaneously. Lighting fixtures are to be mounted at a horizontal separation to ensure an unobstructed view of at least one fixture by a pilot approaching from any direction. Intermediate light levels and other marking may be omitted on these structures.

86. OMISSION OF MARKING

When medium intensity white lights are operated on structures 500 feet (153m) AGL or less during daytime and twilight, other methods of marking may be omitted.

CHAPTER 9. DUAL LIGHTING WITH RED/HIGH INTENSITY FLASHING WHITE SYSTEMS

90. PURPOSE

This dual lighting system includes red lights (L-864) for nighttime and high intensity flashing white lights (L-856) for daytime and twilight use. This lighting system may be used in lieu of operating a flashing white lighting system at night. There may be some populated areas where the use of high intensity lights at night may cause significant environmental concerns and complaints. The use of the dual lighting system should reduce/mitigate those concerns. Recommendations on lighting structures can vary depending on terrain features, weather patterns, geographic location, and in the case of wind turbines, number of structures and overall layout of design.

91. INSTALLATION

The light units should be installed as specified in the appropriate portions of Chapters 4, 5, and 7. The number of light levels needed may be obtained from Appendix 1.

92. OPERATION

Lighting systems should be operated as specified in Chapters 4, 5, and 7. Both systems should not be operated at the same time; however, there should be no more than a 2-second delay when changing from one system to the other. Outage of one of two lamps in the uppermost red beacon (L-864 incandescent unit) or outage of any uppermost red light shall cause the white obstruction light system to operate in its specified "night" step intensity.

93. CONTROL DEVICE

The light intensity is controlled by a device that changes the intensity when the ambient light changes. The system should automatically change intensity steps when the northern sky illumination in the Northern Hemisphere on a vertical surface is as follows:

a. ***Day-to-Twilight***. This should not occur before the illumination drops to 60 foot-candles (645.8 lux) but should occur before it drops below 35 foot-candles (376.7 lux). The illuminance-sensing device should, if practical, face the northern sky in the Northern Hemisphere.

b. ***Twilight-to-Night***. This should not occur before the illumination drops below 5 foot-candles (53.8 lux) but should occur before it drops below 2 foot-candles (21.5 lux).

c. ***Night-to-Day***. The intensity changes listed in subparagraph 93 a and b above should be reversed when changing from the night to day mode.

94. ANTENNA OR SIMILAR APPURTENANCE LIGHT

When a structure utilizing this dual lighting system is topped with an antenna or similar appurtenance exceeding 40 feet (12m) in height, a medium intensity flashing white light (L-865) and a red flashing beacon (L-864) should be placed within 40 feet (12m) from the tip of the appurtenance. The white light should operate during daytime and twilight and the red light during nighttime.

95. OMISSION OF MARKING

When high intensity white lights are operated during daytime and twilight, other methods of marking may be omitted.

CHAPTER 10. MARKING AND LIGHTING OF CATENARY AND CATENARY SUPPORT STRUCTURES

100. PURPOSE

This chapter provides guidelines for marking and lighting catenary and catenary support structures. The recommended marking and lighting of these structures is intended to provide day and night conspicuity and to assist pilots in identifying and avoiding catenary wires and associated support structures.

101. CATENARY MARKING STANDARDS

Lighted markers are available for increased night conspicuity of high-voltage (69KV or greater) transmission line catenary wires. These markers should be used on transmission line catenary wires near airports, heliports, across rivers, canyons, lakes, etc. The lighted markers should be manufacturer certified as recognizable from a minimum distance of 4,000 feet (1219m) under nighttime conditions, minimum VFR conditions or having a minimum intensity of at least 32.5 candela. The lighting unit should emit a steady burning red light. They should be used on the highest energized line. If the lighted markers are installed on a line other than the highest catenary, then markers specified in paragraph 34 should be used in addition to the lighted markers. (The maximum distance between the line energizing the lighted markers and the highest catenary above the lighted marker should be no more than 20 feet (6m).) Markers should be distinctively shaped, i.e., spherical, cylindrical, so they are not mistaken for items that are used to convey other information. They should be visible in all directions from which aircraft are likely to approach. The area in the immediate vicinity of the supporting structure's base should be clear of all items and/or objects of natural growth that could interfere with the line-of-sight between a pilot and the structure's lights. Where a catenary wire crossing requires three or more supporting structures, the inner structures should be equipped with enough light units per level to provide a full coverage.

a. ***Size and Color***. The diameter of the markers used on extensive catenary wires across canyons, lakes, rivers, etc., should be not less than 36 inches (91cm). Smaller 20-inch (51cm) markers are permitted on less extensive power lines or on power lines below 50 feet (15m) above the ground and within 1,500 feet (458m) of an airport runway end. Each marker should be a solid color such as aviation orange, white, or yellow.

b. ***Installation.***

1. ***Spacing.*** Lighted markers should be spaced equally along the wire at intervals of approximately 200 feet (61m) or a fraction thereof. Intervals between markers should be less in critical areas near runway ends, i.e., 30 to 50 feet (10m to 15m). If the markers are installed on a line other than the highest catenary, then markers specified in paragraph 34 should be used in addition to the lighted markers. The maximum distance between the line energizing the lighted markers and the highest catenary above the markers can be no more than 20 feet (6m). The lighted markers may be installed alternately along each wire if the distance between adjacent markers meets the spacing standard. This method allows the weight and wind loading factors to be distributed.

2. ***Pattern***. An alternating color scheme provides the most conspicuity against all backgrounds. Mark overhead wires by alternating solid colored markers of aviation orange, white, and yellow. Normally, an orange marker is placed at each end of a line and the spacing is adjusted (not to exceed 200 feet (61m)) to accommodate the rest of the markers. When less than four markers are used, they should all be aviation orange.

102. CATENARY LIGHTING STANDARDS

When using medium intensity flashing white (L-866), high intensity flashing white (L-857), dual medium intensity (L-866/L-885) or dual high intensity (L-857/885) lighting systems, operated 24 hours a day, other marking of the support structure is not necessary.

a. ***Levels***. A system of three levels of sequentially flashing light units should be installed on each supporting structure or adjacent terrain. Install one level at the top of the structure, one at the height of the lowest point in the catenary and one level approximately midway between the other two light levels. The middle level should normally be at least 50 feet (15m) from the other two levels. The middle light unit may be deleted when the distance between the top and the bottom light levels is less than 100 feet (30m).

1. ***Top Levels***. One or more lights should be installed at the top of the structure to provide 360-degree coverage ensuring an unobstructed view. If the installation presents a potential danger to maintenance personnel, or when necessary for lightning protection, the top level of lights may be mounted as low as 20 feet (6m) below the highest point of the structure.

2. ***Horizontal Coverage***. The light units at the middle level and bottom level should be installed so as to provide a minimum of 180-degree coverage centered perpendicular to the flyway. Where a

catenary crossing is situated near a bend in a river, canyon, etc., or is not perpendicular to the flyway, the horizontal beam should be directed to provide the most effective light coverage to warn pilots approaching from either direction of the catenary wires.

3. ***Variation.*** The vertical and horizontal arrangements of the lights may be subject to the structural limits of the towers and/or adjacent terrain. A tolerance of 20 percent from uniform spacing of the bottom and middle light is allowed. If the base of the supporting structure(s) is higher than the lowest point in the catenary, such as a canyon crossing, one or more lights should be installed on the adjacent terrain at the level of the lowest point in the span. These lights should be installed on the structure or terrain at the height of the lowest point in the catenary.

b. ***Flash Sequence.*** The flash sequence should be middle, top, and bottom with all lights on the same level flashing simultaneously. The time delay between flashes of levels is designed to present a unique system display. The time delay between the start of each level of flash duration is outlined in FAA AC 150/5345-43, Specification for Obstruction Lighting Equipment.

c. ***Synchronization.*** Although desirable, the corresponding light levels on associated supporting towers of a catenary crossing need not flash simultaneously.

d. ***Structures 500 feet (153m) AGL or Less.*** When medium intensity white lights (L-866) are operated 24 hours a day, or when a dual red/medium intensity system (L-866 daytime & twilight/L-885 nighttime) is used, marking can be omitted. When using a medium intensity while light (L-866) or a flashing red light (L-885) during twilight or nighttime only, painting should be used for daytime marking.

e. *Structures Exceeding 500 Feet (153m) AGL.* When high intensity white lights (L-857) are operated 24 hours a day, or when a dual red/high intensity system (L-857 daytime and twilight/L-885 nighttime) is used, marking can be omitted. This system should not be recommended on structures 500 feet (153m) or less unless an FAA aeronautical study shows otherwise. When a flashing red obstruction light (L-885), a medium intensity (L-866) flashing white lighting system or a high intensity white lighting system (L-857) is used for nighttime and twilight only, painting should be used for daytime marking.

103. CONTROL DEVICE

The light intensity is controlled by a device (photocell) that changes the intensity when the ambient light changes. The lighting system should automatically change intensity steps when the northern sky illumination in the Northern Hemisphere on a vertical surface is as follows:

a. ***Day-to-Twilight (L-857 System).*** This should not occur before the illumination drops to 60 foot-candles (645.8 lux), but should occur before it drops below 35 foot-candles (376.7 lux). The illuminant-sensing device should, if practical, face the northern sky in the Northern Hemisphere.

b. ***Twilight-to-Night (L-857 System).*** This should not occur before the illumination drops below 5 foot-candles (53.8 lux), but should occur before it drops below 2 foot-candles (21.5 lux).

c. ***Night-to-Day.*** The intensity changes listed in subparagraph 103 a. and b. above should be reversed when changing from the night to day mode.

d. ***Day-to-Night (L-866 or L-885/L-866).*** This should not occur before the illumination drops below 5 foot-candles (563.8 lux) but should occur before it drops below 2 foot-candles (21.5 lux).

e. ***Night-to-Day.*** The intensity changes listed in subparagraph d. above should be reversed when changing from the night to day mode.

f. ***Red Obstruction (L-885).*** The red lights should not turn on until the illumination drops below 60 foot-candles (645.8 lux) but should occur before reaching a level of 35 foot-candles (367.7 lux). Lights should not turn off before the illuminance rises above 35 foot-candles (367.7 lux), but should occur before reaching 60 foot-candles (645.8 lux).

104. AREA SURROUNDING CATENARY SUPPORT STRUCTURES

The area in the immediate vicinity of the supporting structure's base should be clear of all items and/or objects of natural growth that could interfere with the line-of-sight between a pilot and the structure's lights.

105. THREE OR MORE CATENARY SUPPORT STRUCTURES

Where a catenary wire crossing requires three or more supporting structures, the inner structures should be equipped with enough light units per level to provide a full 360-degree coverage.

CHAPTER 11. MARKING AND LIGHTING MOORED BALLOONS AND KITES

110. PURPOSE

The purpose of marking and lighting moored balloons, kites, and their cables or mooring lines is to indicate the presence and general definition of these objects to pilots when converging from any normal angle of approach.

111. STANDARDS

These marking and lighting standards pertain to all moored balloons and kites that require marking and lighting under 14 CFR, part 101.

112. MARKING

Flag markers should be used on mooring lines to warn pilots of their presence during daylight hours.

a. ***Display.*** Markers should be displayed at no more than 50-foot (15m) intervals and should be visible for at least 1 statute mile.

b. ***Shape.*** Markers should be rectangular in shape and not less than 2 feet (0.6m) on a side. Stiffeners should be used in the borders so as to expose a large area, prevent drooping in calm wind, or wrapping around the cable.

c. ***Color Patterns.*** One of the following color patterns should be used:

1. ***Solid Color.*** Aviation orange.

2. ***Orange and White.*** Two triangular sections, one of aviation orange and the other white, combined to form a rectangle.

113. PURPOSE

Flashing obstruction lights should be used on moored balloons or kites and their mooring lines to warn pilots of their presence during the hours between sunset and sunrise and during periods of reduced visibility. These lights may be operated 24 hours a day.

a. ***Systems.*** Flashing red (L-864) or white beacons (L-865) may be used to light moored balloons or kites. High intensity lights (L-856) are not recommended.

b. ***Display.*** Flashing lights should be displayed on the top, nose section, tail section, and on the tether cable approximately 15 feet (4.6m) below the craft so as to define the extremes of size and shape. Additional lights should be equally spaced along the cable's overall length for each 350 feet (107m) or fraction thereof.

c. ***Exceptions.*** When the requirements of this paragraph cannot be met, floodlighting may be used.

114. OPERATIONAL CHARACTERISTICS

The light intensity is controlled by a device that changes the intensity when the ambient light changes. The system should automatically turn the lights on and change intensities as ambient light condition change. The reverse order should apply in changing from nighttime to daytime operation. The lights should flash simultaneously.

CHAPTER 12. MARKING AND LIGHTING EQUIPMENT AND INFORMATION

120. PURPOSE

This chapter lists documents relating to obstruction marking and lighting systems and where they may be obtained.

121. PAINT STANDARD

Paint and aviation colors/gloss, referred to in this publication should conform to Federal Standard FED-STD-595. Approved colors shall be formulated without the use of Lead, Zinc Chromate or other heavy metals to match International Orange, White and Yellow. All coatings shall be manufactured and labeled to meet Federal Environmental Protection Act Volatile Organic Compound(s) guidelines, including the National Volatile Organic Compound Emission Standards for architectural coatings.

a. **Exterior Acrylic Waterborne Paint.** Coating should be a ready mixed, 100% acrylic, exterior latex formulated for application directly to galvanized surfaces. Ferrous iron and steel or non-galvanized surfaces shall be primed with a manufacturer recommended primer compatible with the finish coat.

b. **Exterior Solventborne Alkyd Based Paint.** Coating should be ready mixed, alkyd-based, exterior enamel for application directly to non-galvanized surfaces such as ferrous iron and steel. Galvanized surfaces shall be primed with a manufacturer primer compatible with the finish coat.

Paint Standards Color Table

COLOR	NUMBER
Orange	12197
White	17875
Yellow	13538

TBL 3

Note-
1. Federal specification TI-P-59, aviation surface paint, ready mixed international orange.

2. Federal specification TI-102, aviation surface paint, oil titanium zinc.

3. Federal specification TI-102, aviation surface paint, oil, exterior, ready mixed, white and light tints.

122. AVAILABILITY OF SPECIFICATIONS

Federal specifications describing the technical characteristics of various paints and their application techniques may be obtained from:

GSA- Specification Branch
470 L'Enfant Plaza
Suite 8214
Washington, DC 20407
Telephone: (202) 619-8925

123. LIGHTS AND ASSOCIATED EQUIPMENT

The lighting equipment referred to in this publication should conform to the latest edition of one of the following specifications, as applicable:

a. ***Obstruction Lighting Equipment.***

1. AC 150/5345-43, FAA Specification for Obstruction Lighting Equipment.

2. Military Specifications MIL-L-6273, Light, Navigational, Beacon, Obstacle or Code, Type G-1.

3. Military Specifications MIL-L-7830, Light Assembly, Markers, Aircraft Obstruction.

b. ***Certified Equipment.***

1. AC 150/5345-53, Airport Lighting Certification Program, lists the manufacturers that have demonstrated compliance with the specification requirements of AC 150/5345-43.

2. Other manufacturers' equipment may be used provided that equipment meets the specification requirements of AC 150/5345-43.

c. ***Airport Lighting Installation and Maintenance.***

1. AC 150/5340-21, Airport Miscellaneous Lighting Visual Aids, provides guidance for the installation, maintenance, testing, and inspection of obstruction lighting for airport visual aids such as airport beacons, wind cones, etc.

2. AC 150/5340-26, Maintenance of Airport Visual Aid Facilities, provides guidance on the maintenance of airport visual aid facilities.

d. ***Vehicles.***

1. AC 150/5210-5, Painting, Marking, and Lighting of Vehicles Used on an Airport, contains provisions for marking vehicles principally used on airports.

2. FAA Facilities. Obstruction marking for FAA facilities shall conform to FAA Drawing Number D-5480, referenced in FAA Standard FAA-STD-003, Paint Systems for Structures.

124. AVAILABILITY

The standards and specifications listed above may be obtained free of charge from the below-indicated office:

a. ***Military Specifications:***

Standardization Document Order Desk 700 Robbins Avenue Building #4, Section D Philadelphia, PA 19111-5094

b. ***FAA Specifications:***

Manager, ASD-110 Department of Transportation Document Control Center Martin Marietta/Air Traffic Systems 475 School St., SW. Washington, DC 20024 Telephone: (202) 646-2047 FAA Contractors Only

c. ***FAA Advisory Circulars:***

Department of Transportation TASC Subsequent Distribution Office, SVC-121.23 Ardmore East Business Center 3341 Q 75th Avenue Landover, MD 20785 Telephone: (301) 322-4961

APPENDIX 1: Specifications for Obstruction Lighting Equipment Classification

APPENDIX

Type	Description
L-810	Steady-burning Red Obstruction Light
L-856	High Intensity Flashing White Obstruction Light (40 FPM)
L-857	High Intensity Flashing White Obstruction Light (60 FPM)
L-864	Flashing Red Obstruction Light (20-40 FPM)
L-865	Medium Intensity Flashing White Obstruction Light (40-FPM)
L-866	Medium Intensity Flashing White Obstruction Light (60-FPM)
L-864/L-865	Dual: Flashing Red Obstruction Light (20-40 FPM) and Medium Intensity Flashing White Obstruction Light (40 FPM)
L-885	Red Catenary 60 FPM
FPM = Flashes Per Minute	

TBL 4

PAINTING AND/OR DUAL LIGHTING OF CHIMNEYS, POLES, TOWERS, AND SIMILAR STRUCTURES

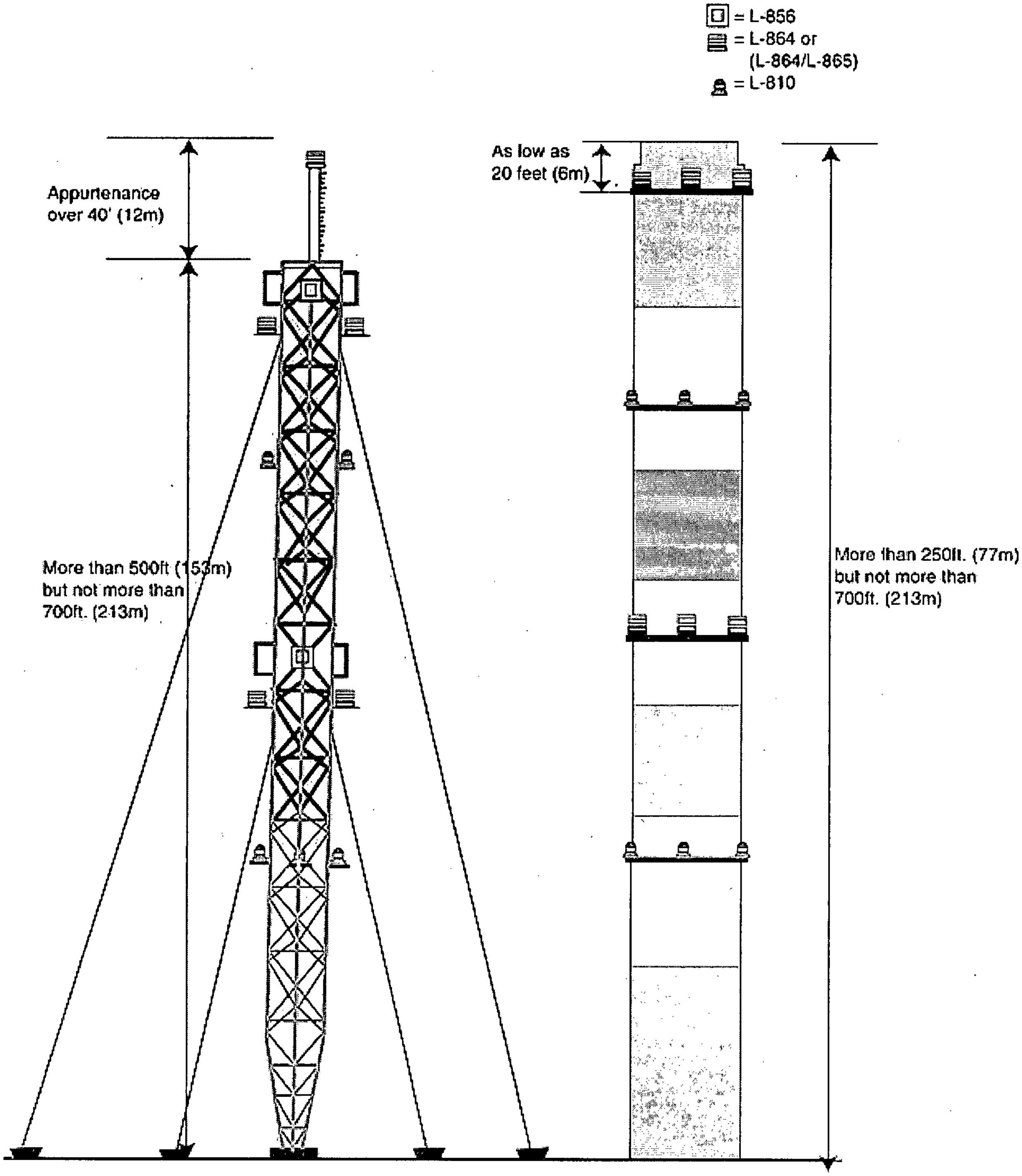
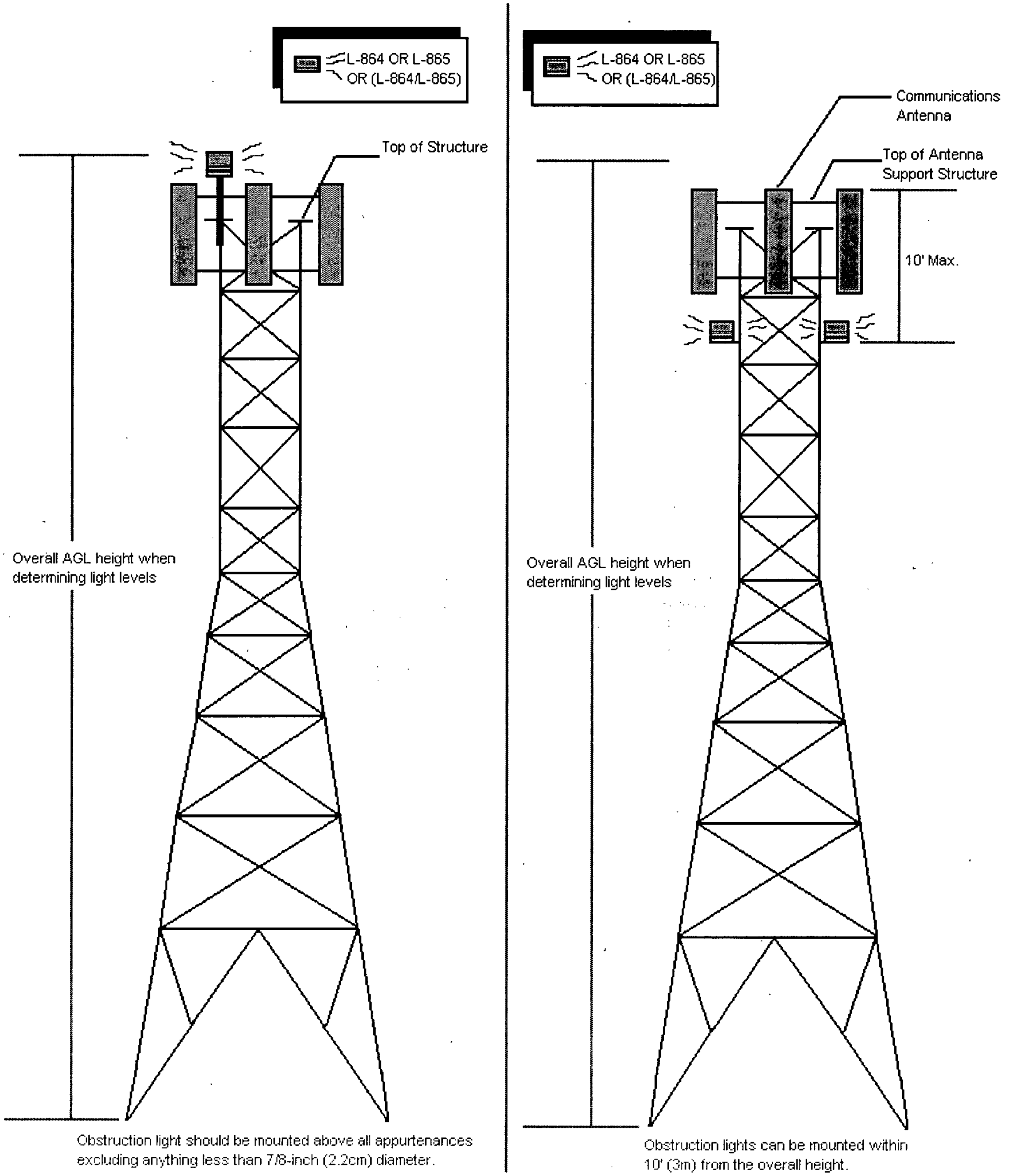


FIG 1

LIGHTING FOR TOP OF STRUCTURES



Intermediate lighting not shown. Overall AGL height if more than 200' (61m), but not more than 500' (153m).

FIG 2

PAINTING AND LIGHTING OF WATER TOWERS, STORAGE TANKS, AND SIMILAR STRUCTURES

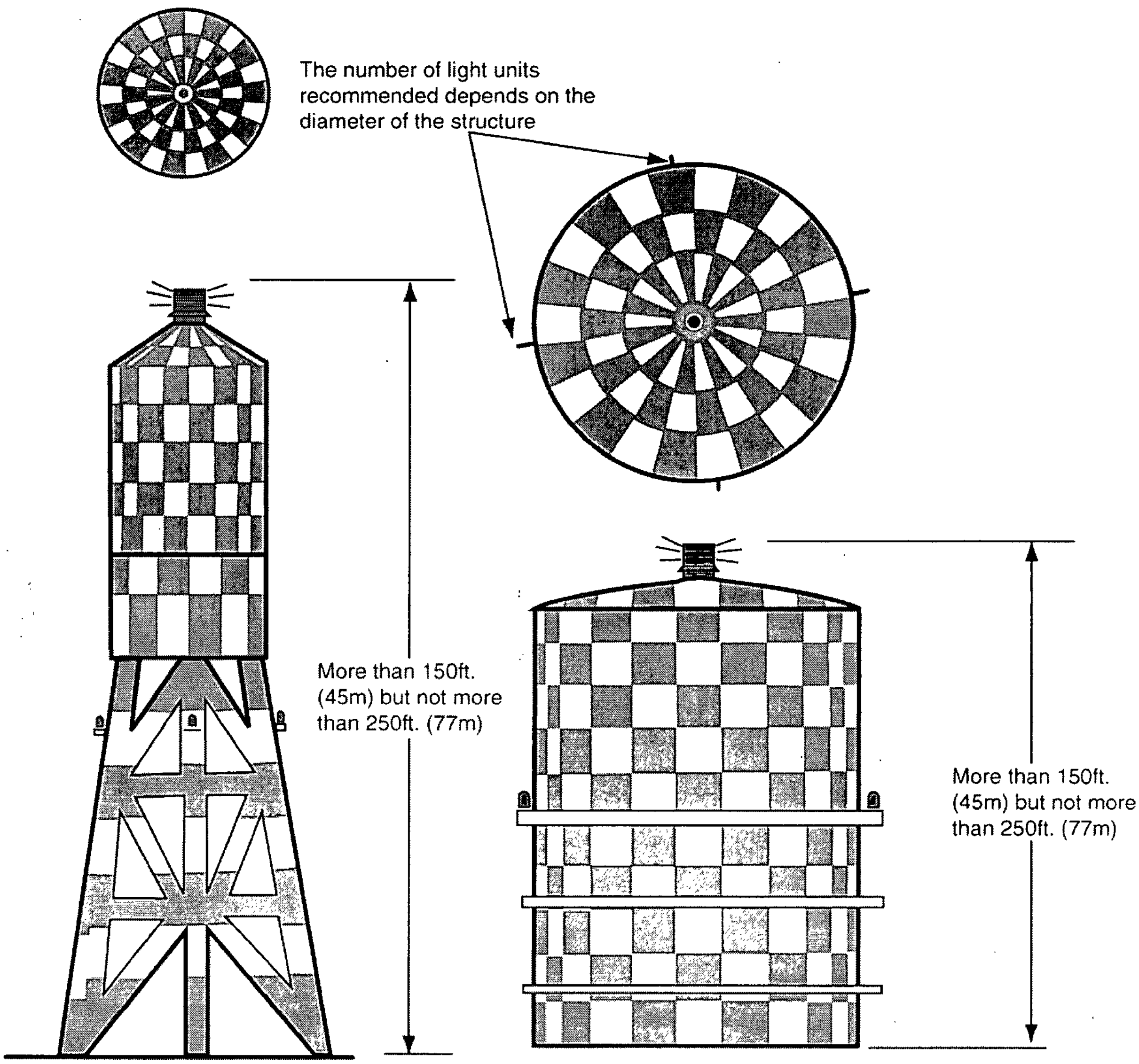


FIG 3

PAINTING AND LIGHTING OF WATER TOWERS ANDE SIMILAR STRUCTURES

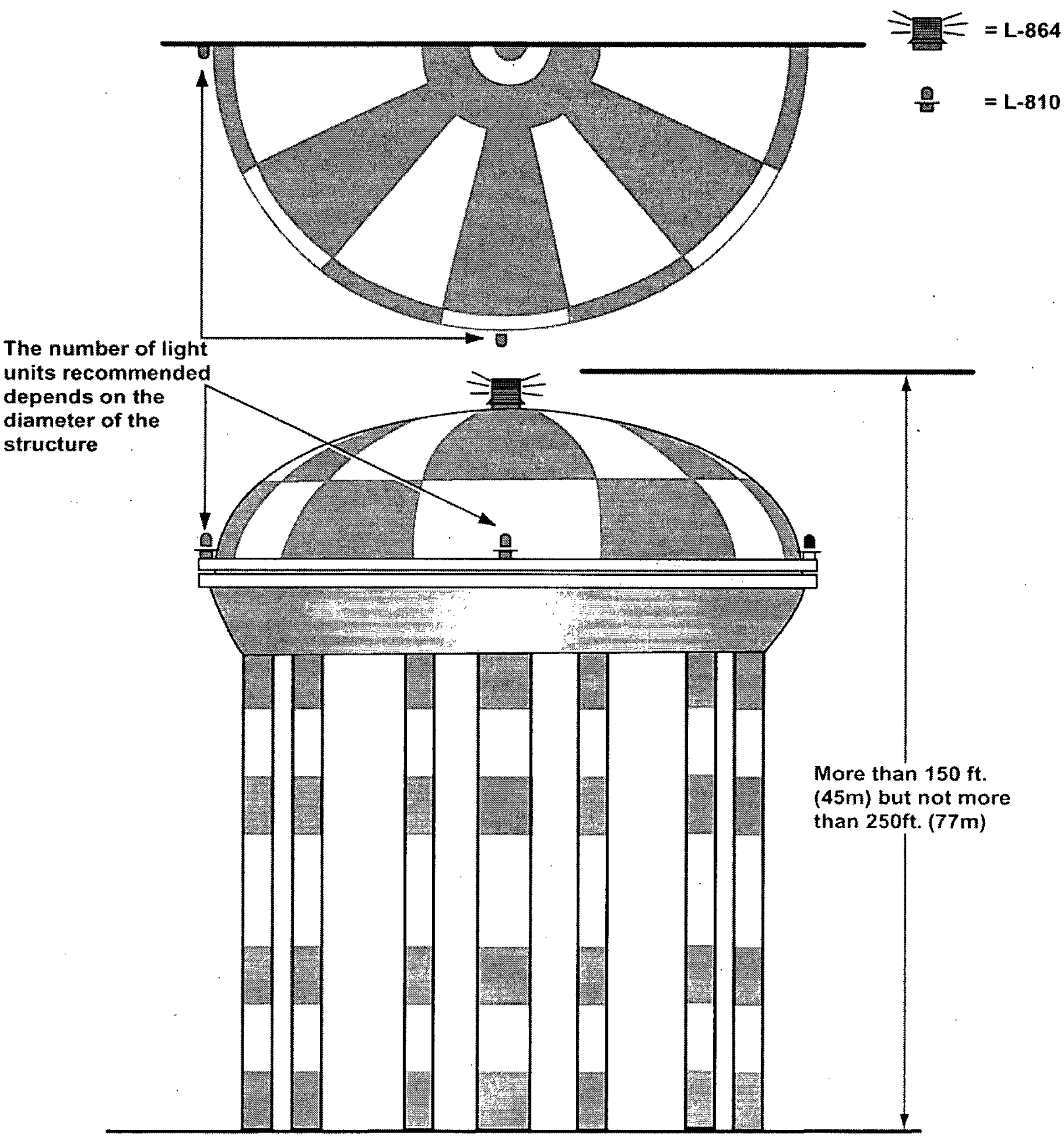


FIG 4

PAINTING OF SINGLE PEDESTAL WATER TOWER BY TEARDROP PATTERN

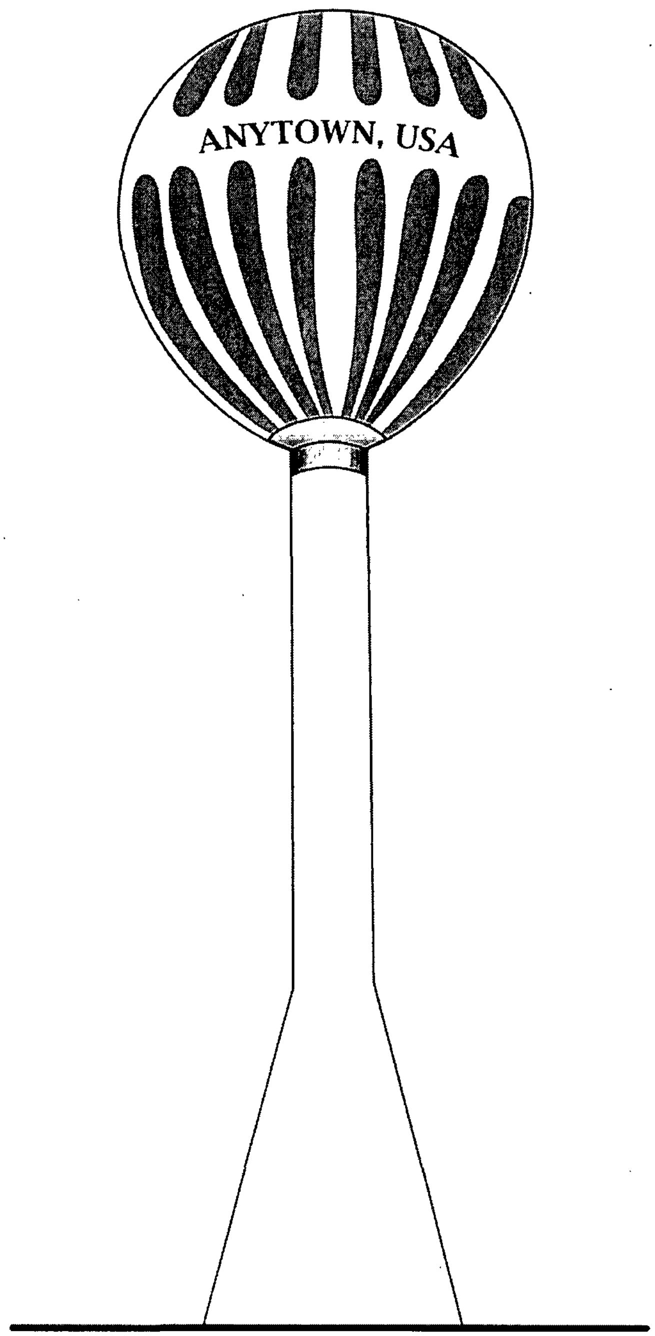
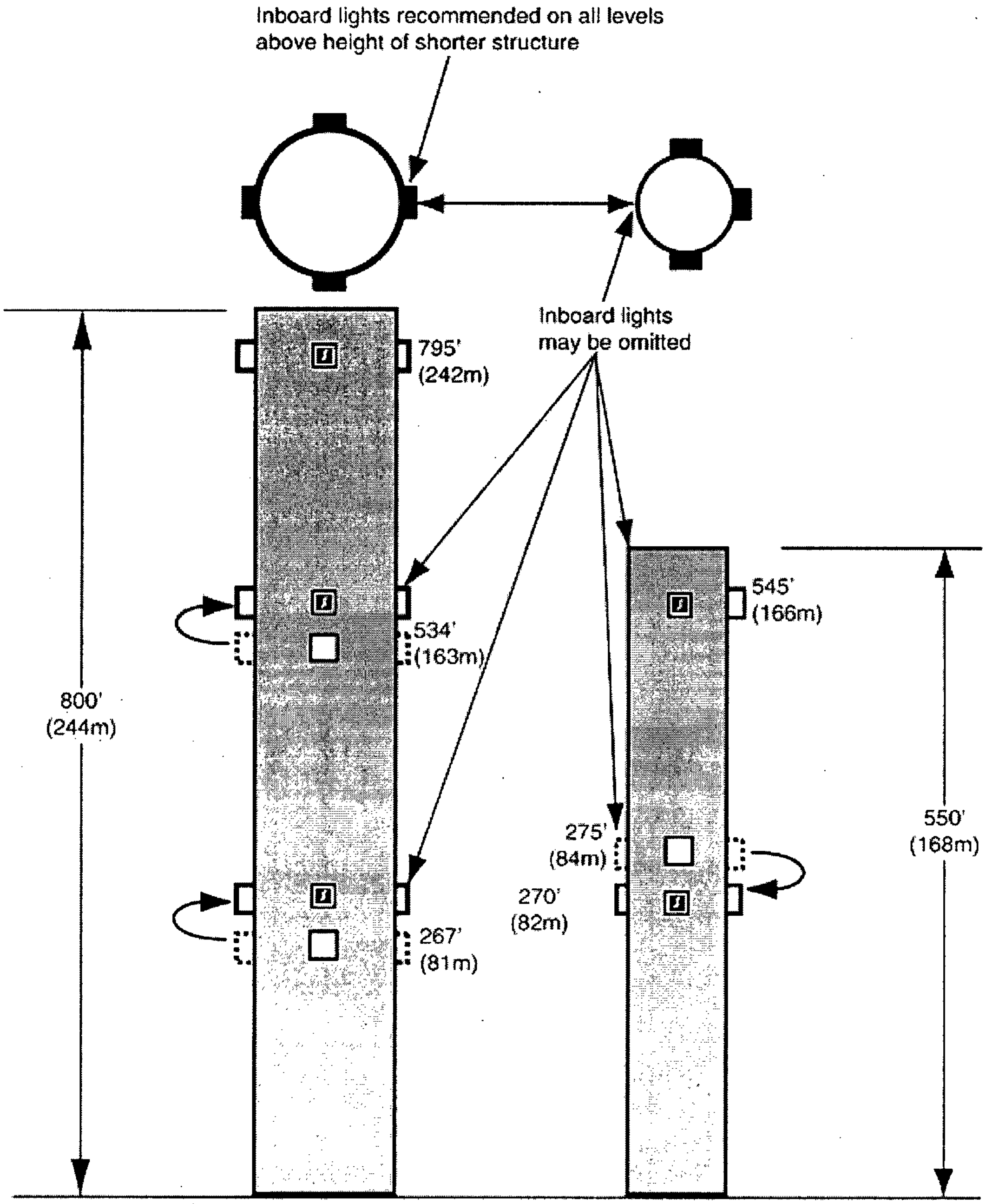


FIG 5

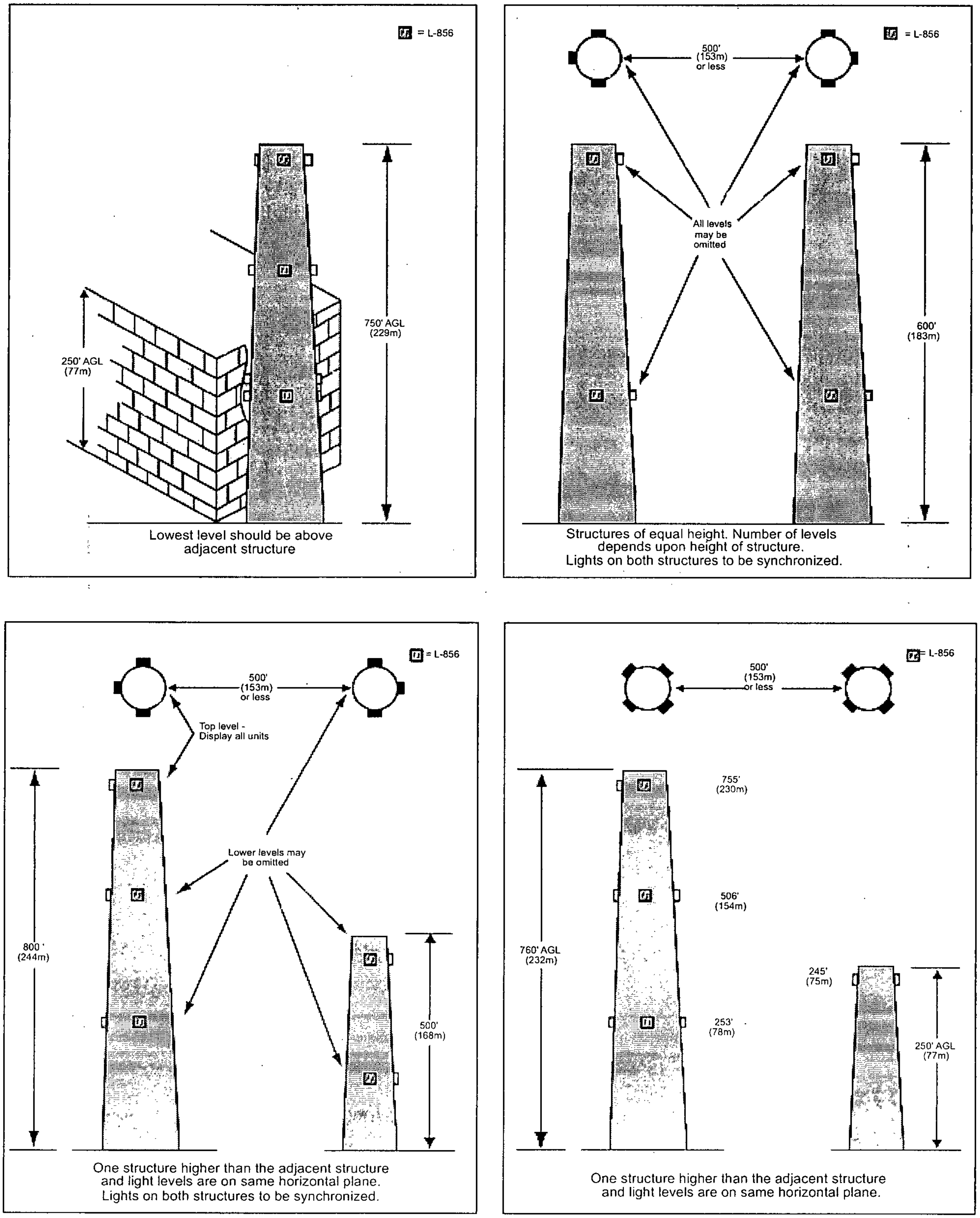
LIGHTING ADJACENT STRUCTURES



Minor adjustments in vertical placement may be made to place lights on same horizontal plane. Lights on both structures be synchronized

FIG 6

Lighting Adjacent Structure



Lowest level should be above adjacent structure

Structures of equal height. Number of levels depends upon height of structure. Lights on both structures to be synchronized.

One structure higher than the adjacent structure and light levels are on same horizontal plane. Lights on both structures to be synchronized.

One structure higher than the adjacent structure and light levels are on same horizontal plane.

FIG 7

Lighting Adjacent Structure

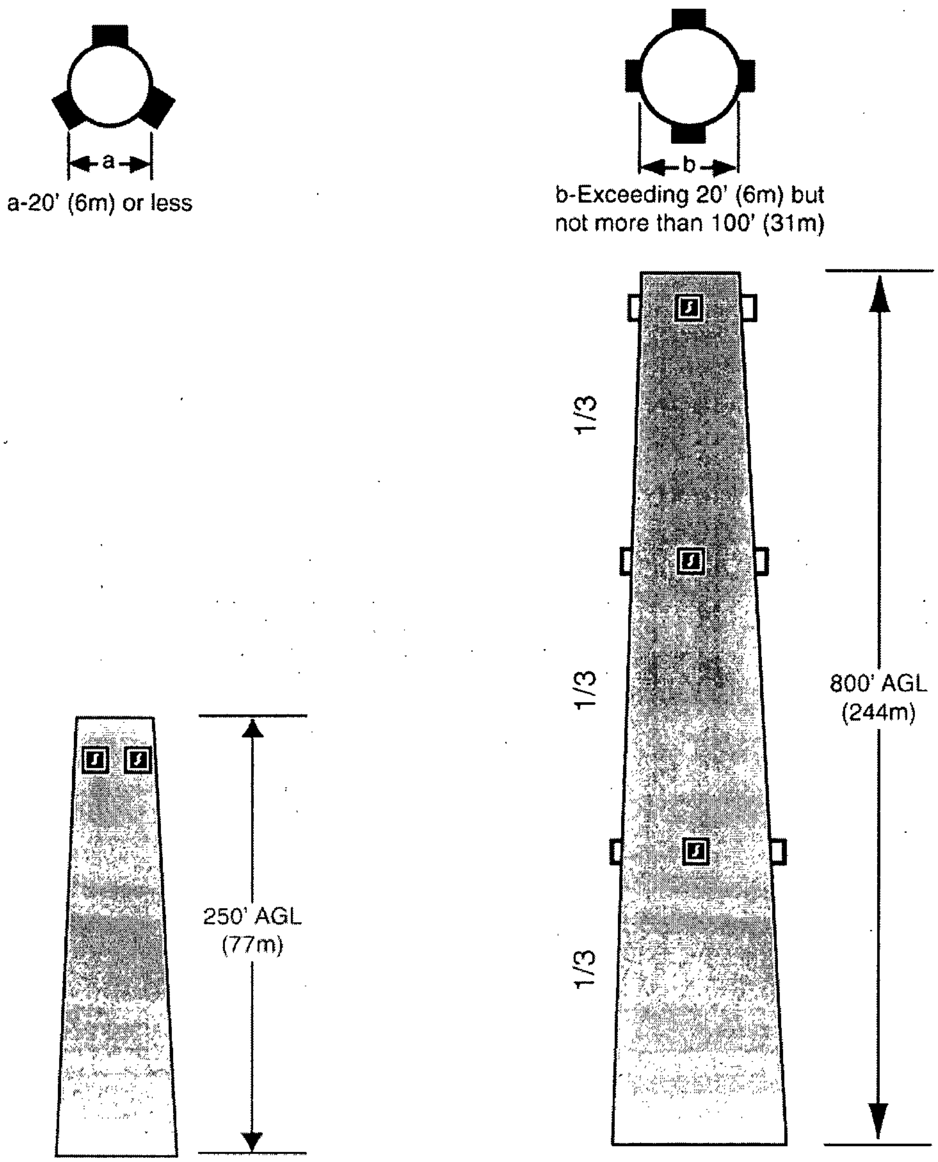


FIG 8

HYPERBOLIC COOLING TOWER

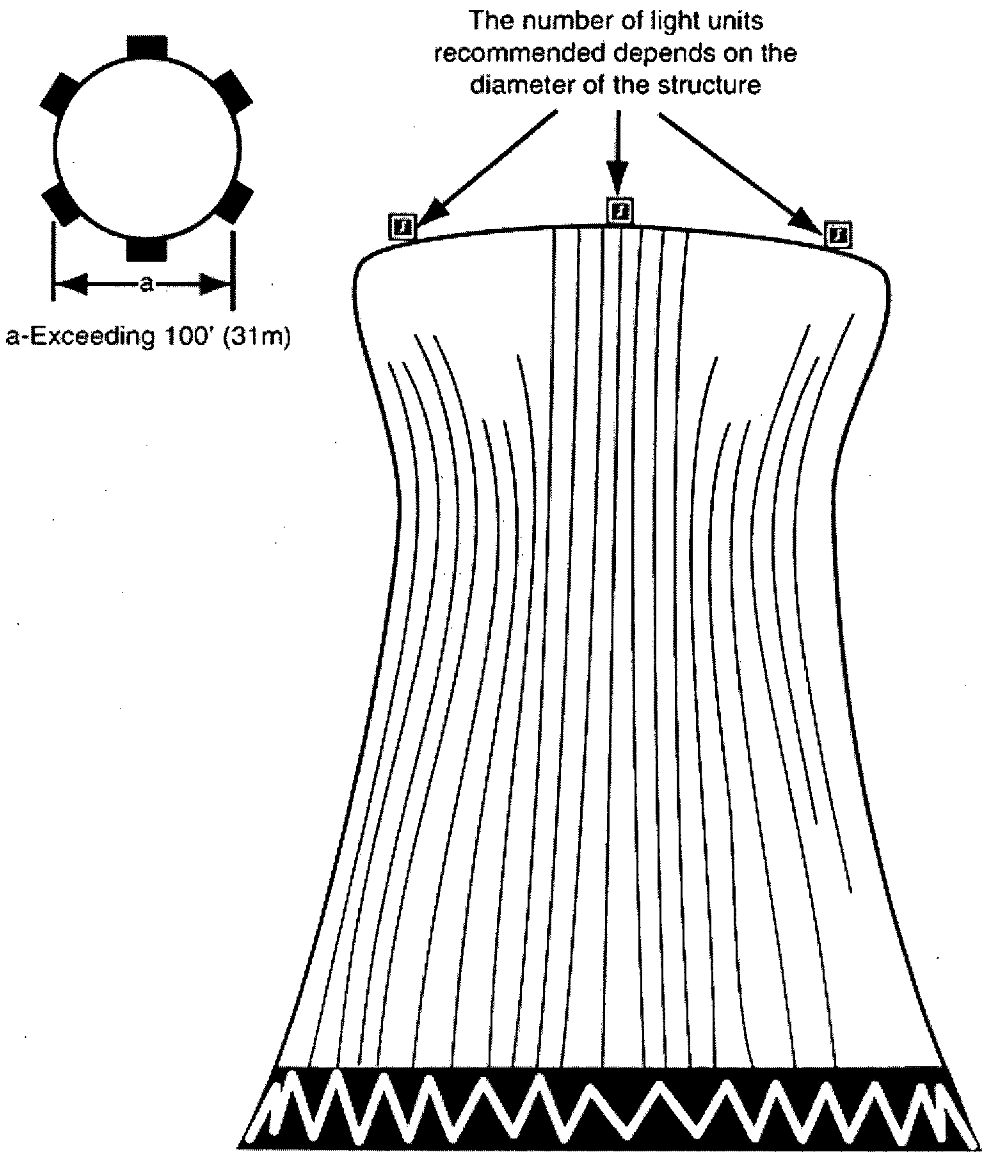


FIG 9

BRIDGE LIGHTING

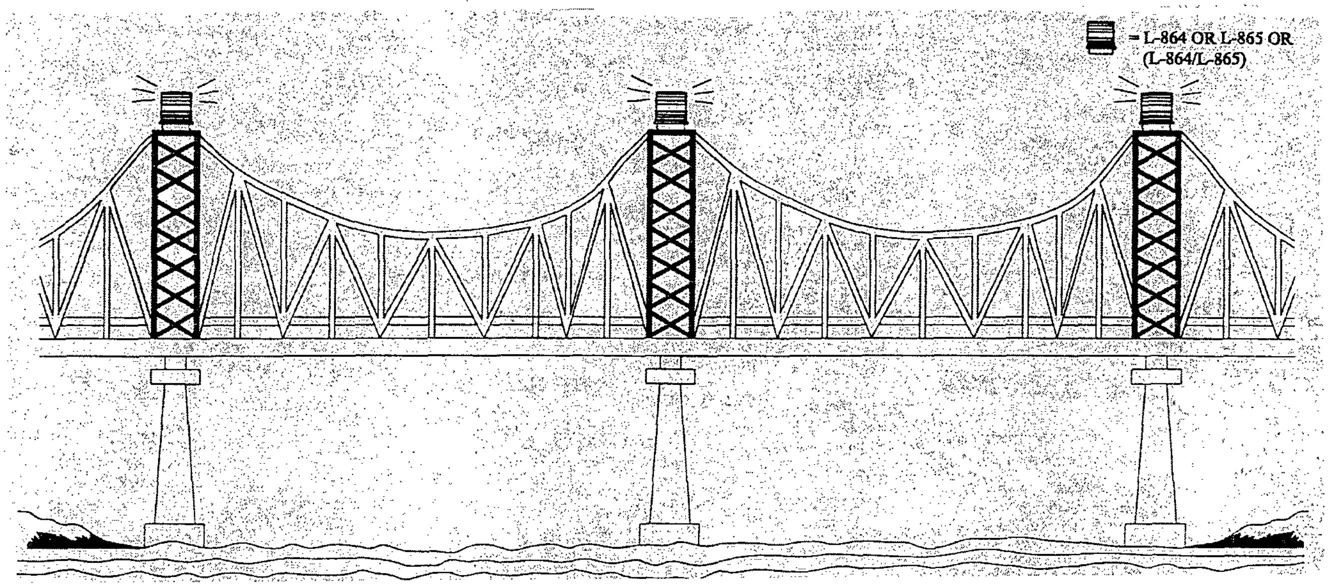


FIG 10

TYPICAL LIGHTING OF A STAND ALONE WIND TURBINE

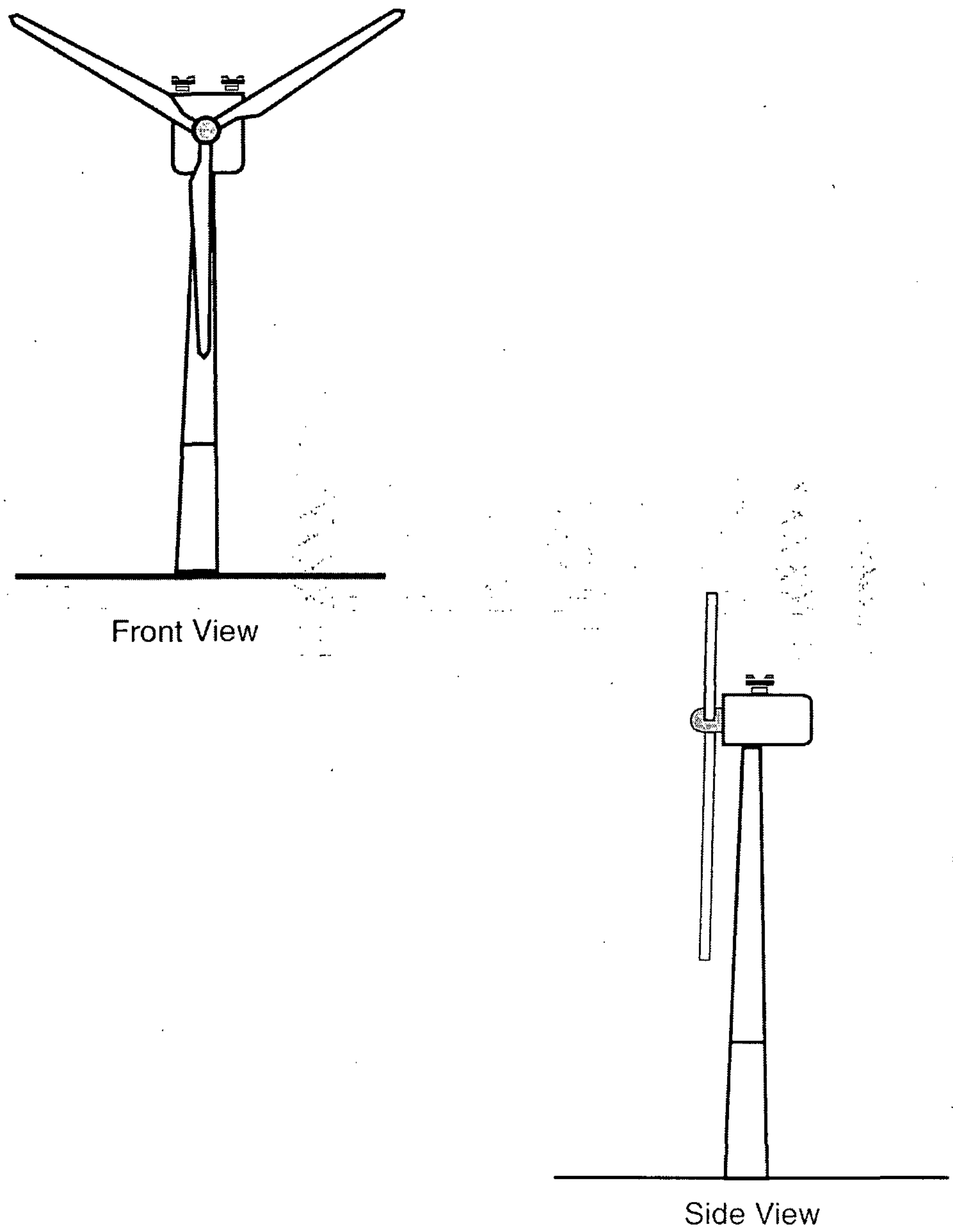


FIG 11

WIND TURBINE GENERATOR

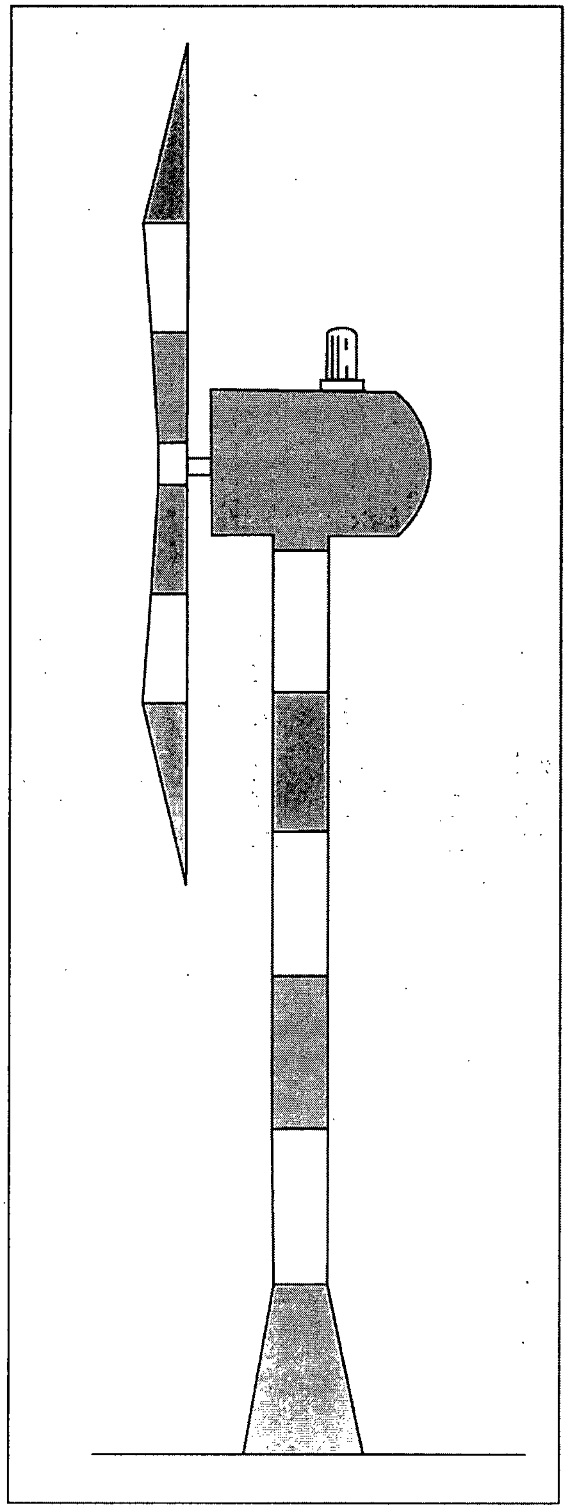


FIG 12

RED OBSTRUCTION LIGHTING STANDARDS (FAA Style A)

Day Protection = Aviation Orange/White Paint
Night Protection = 2,000cd Red Beacon and sidelights

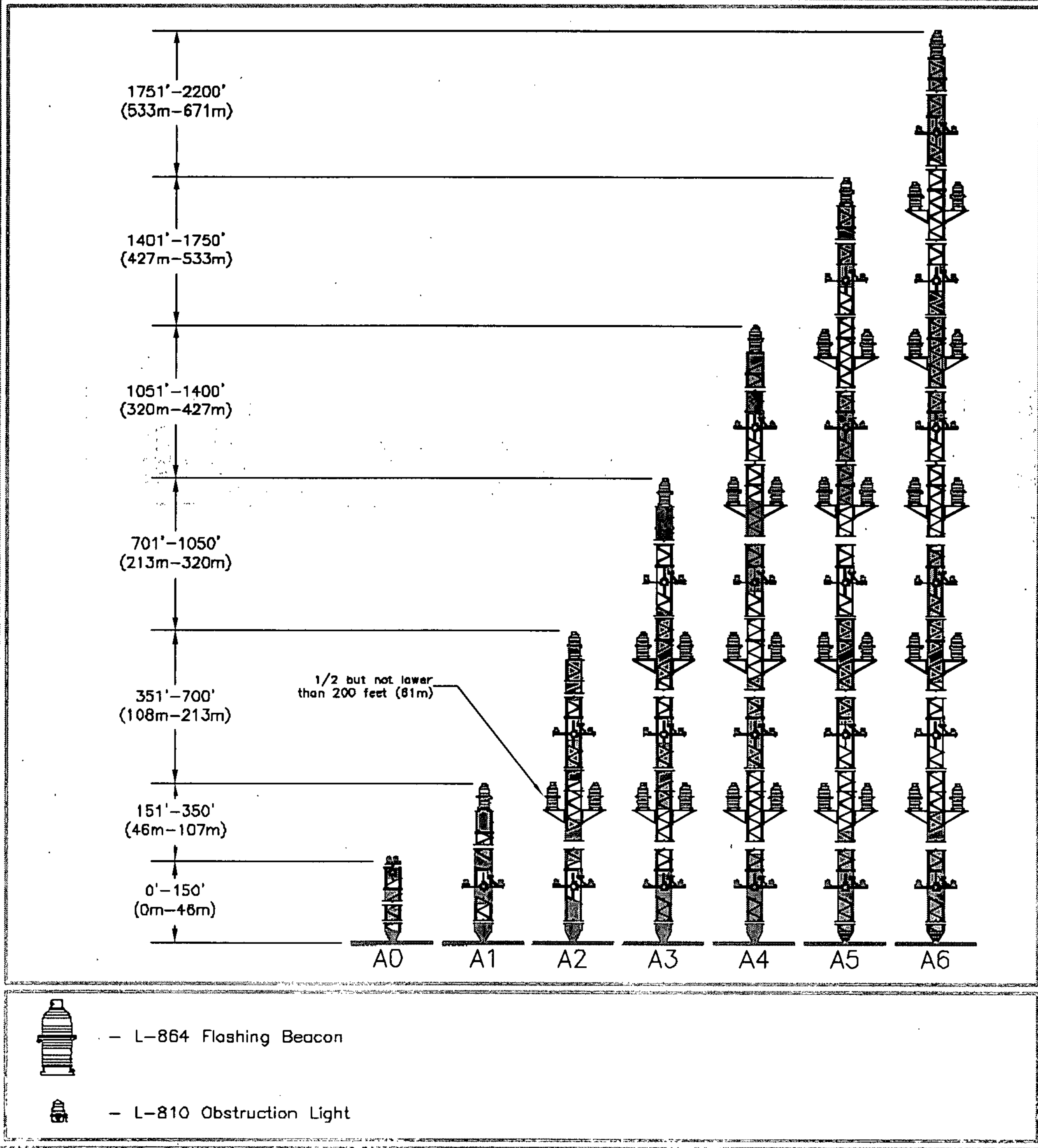


FIG 13

MEDIUM INTENSITY WHITE OBSTRUCTION LIGHTING STANDARDS (FAA Style D)

Day/Twilight Protection = 20,000cd White Strobe
Night Protection = 2,000cd White Strobe
Painting of tower is typically not required.

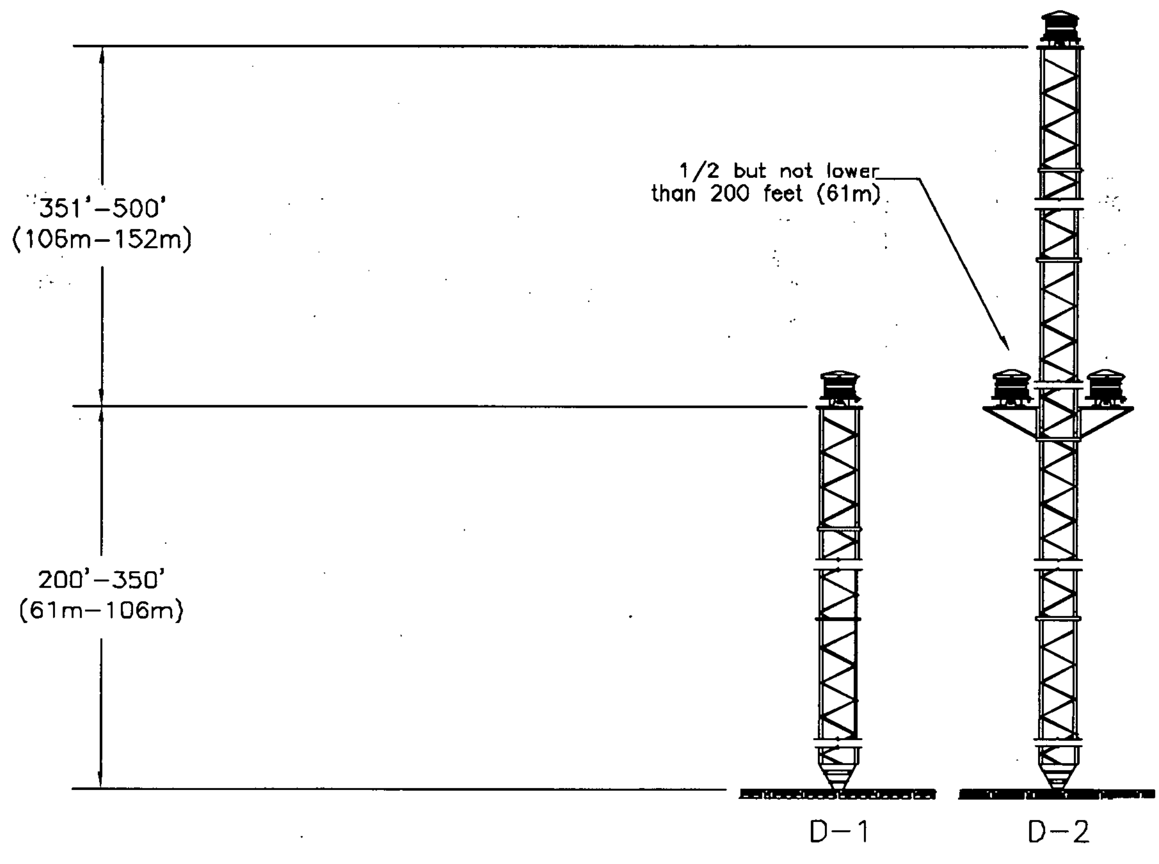


FIG 14

HIGH INTENSITY OBSTRUCTION LIGHTING STANDARDS (FAA Style B)

Day Protection = 200,000cd White Strobe
Twilight Protection = 20,000cd White Strobe
Night Protection = 2,000cd White Strobe

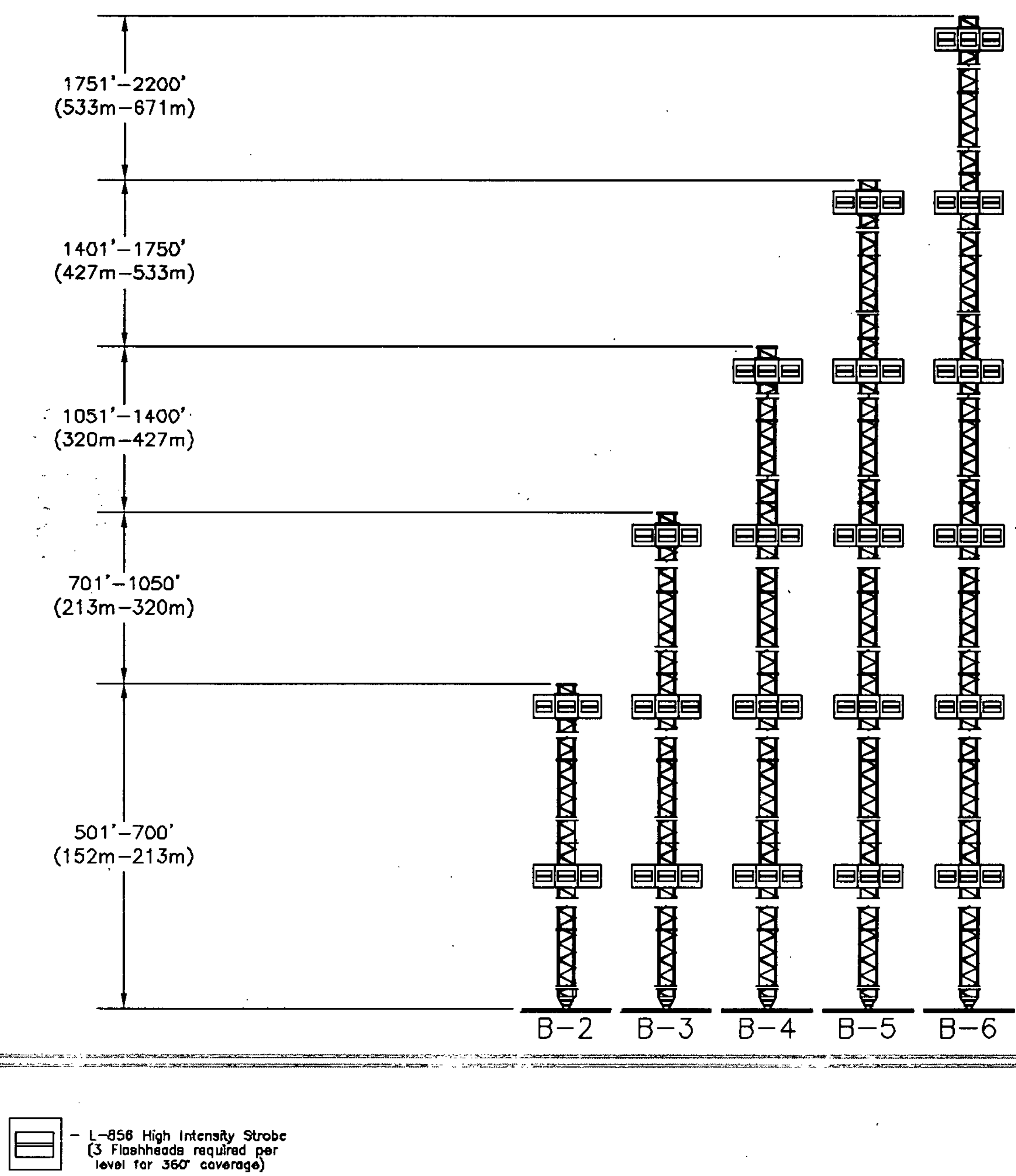
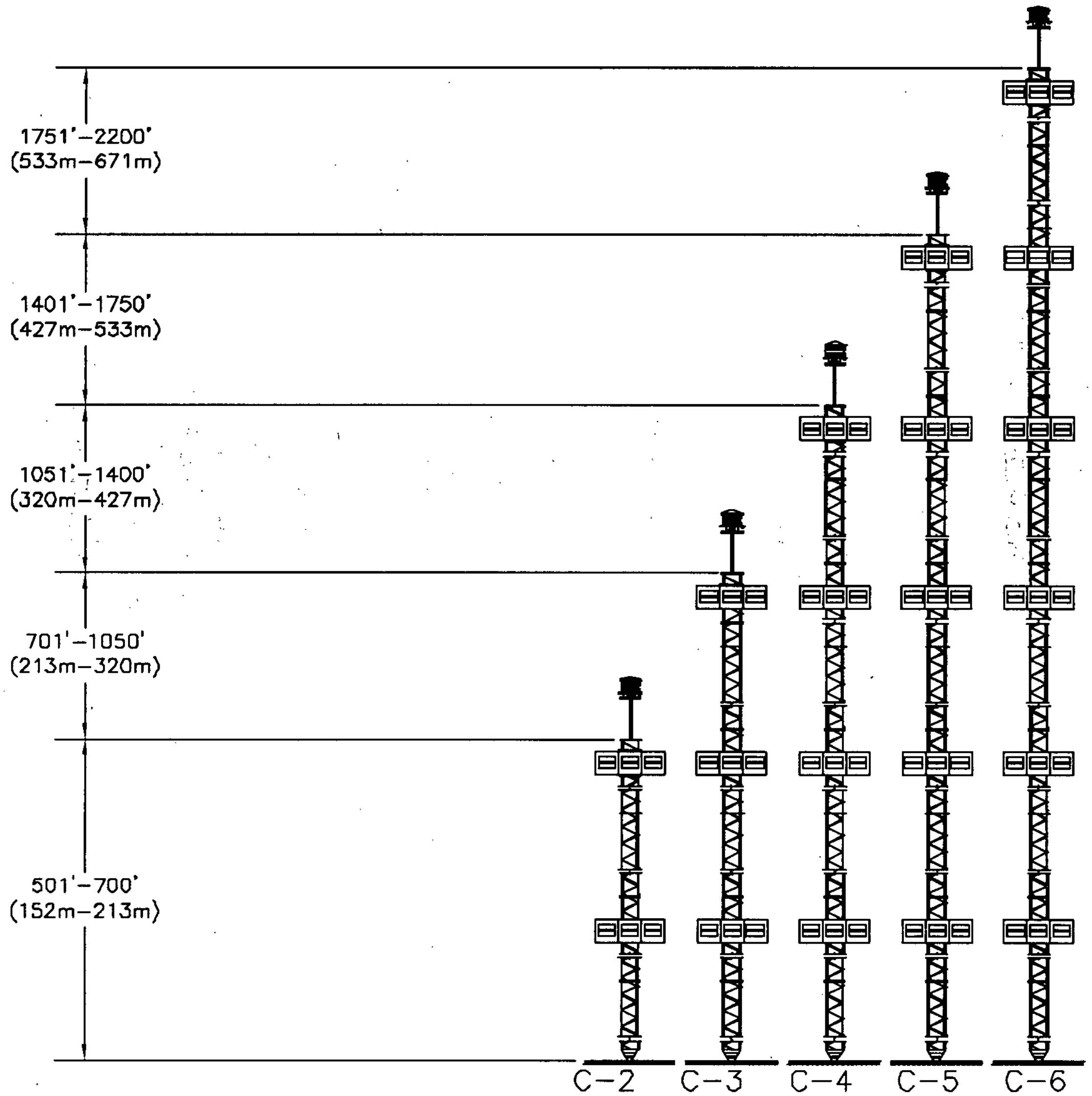


FIG 15

HIGH INTENSITY OBSTRUCTION LIGHTING STANDARDS (FAA Style C)

Day Protection = 200,000cd White Strobe
Twilight Protection = 20,000cd White Strobe
Night Protection = 2,000cd White Strobe



– L–856 High Intensity Strobe (3 Flashheads required per level for 360° coverage)

– L–865 Medium Intensity Strobe required for appurtenances of 40 feet or greater.

FIG 16

MEDIUM INTENSITY DUAL OBSTRUCTION LIGHTING STANDARDS (FAA Style E)

Day/Twilight Protection = 20,000cd White Strobe
Night Protection = 2,000cd Red Strobe and sidelights
Painting of tower is typically not required.

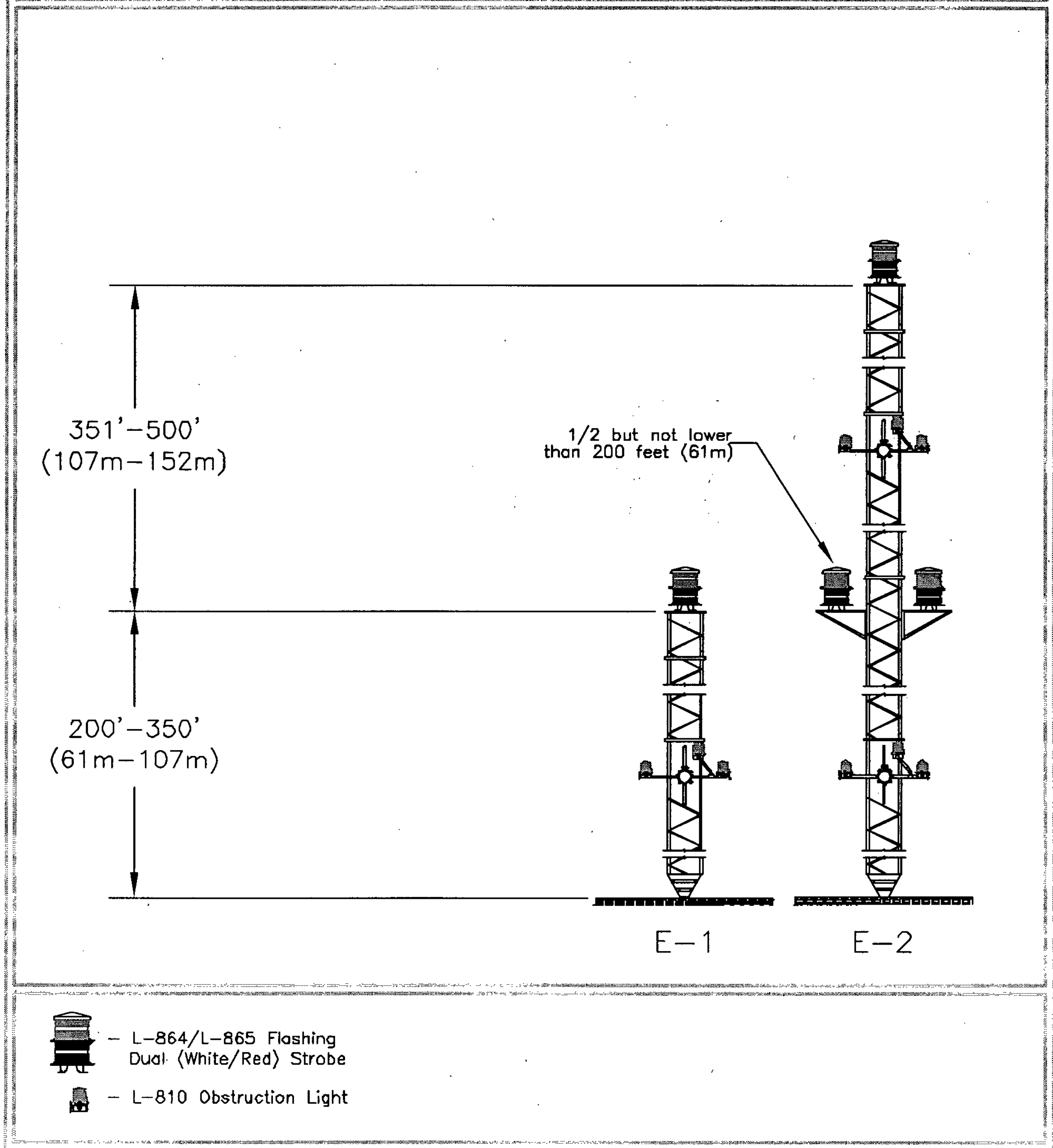


FIG 17

DUAL HIGH INTENSITY OBSTRUCTION LIGHTING STANDARDS (FAA Style F)

Day Protection = 200,000cd White Strobe
Twilight Protection = 20,000cd White Strobe
Night Protection = 2,000cd Red Beacon and sidelights

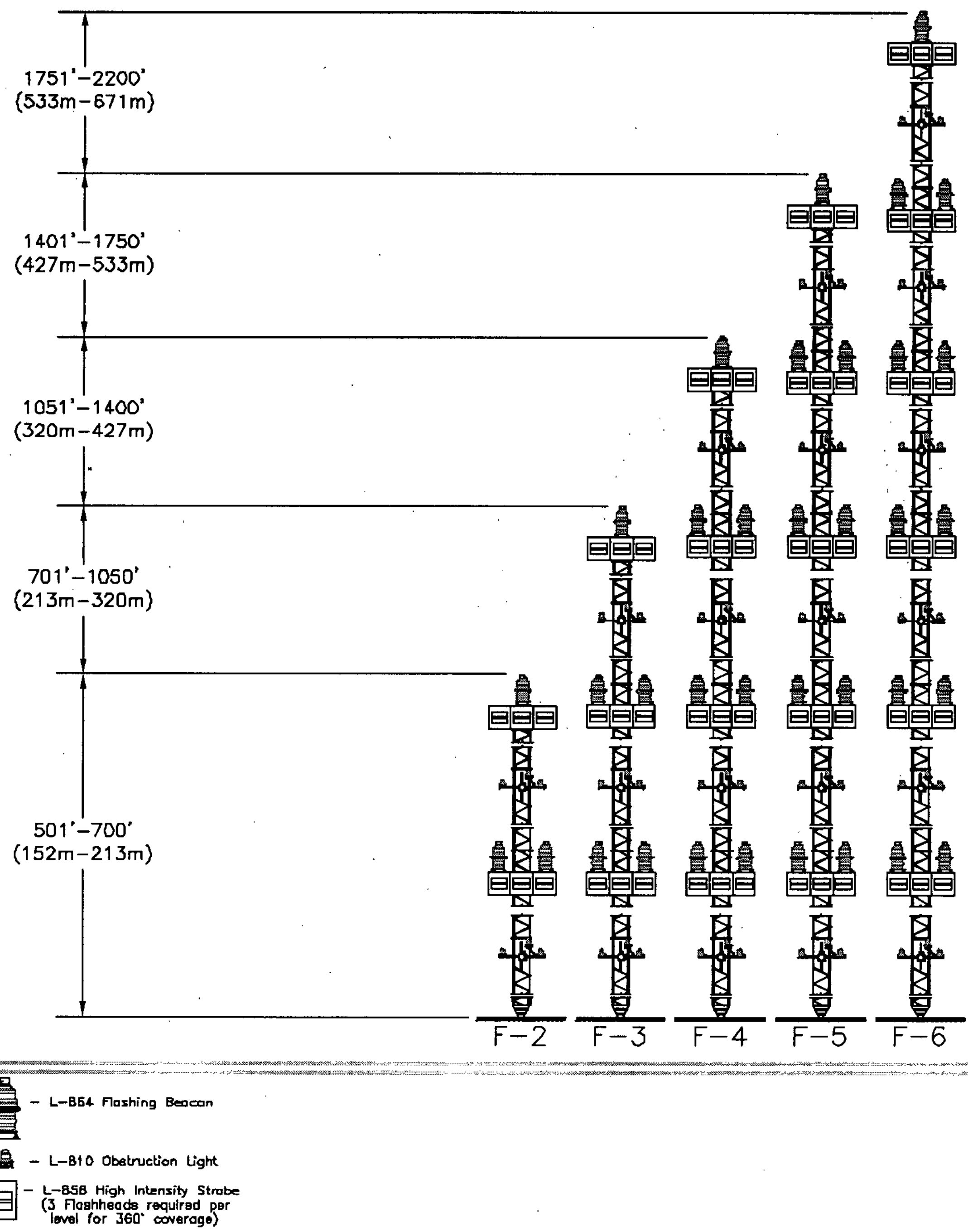


FIG 18

APPENDIX 2. Miscellaneous

1. RATIONALE FOR OBSTRUCTION LIGHT INTENSITIES.

Sections 91.117, 91.119 and 91.155 of the FAR Part 91, General Operating and Flight Rules, prescribe aircraft speed restrictions, minimum safe altitudes, and basic visual flight rules (VFR) weather minimums for governing the operation of aircraft, including helicopters, within the United States.

2. DISTANCE VERSUS INTENSITIES.

TBL 5 depicts the distance the various intensities can be seen under 1 and 3 statute miles meteorological visibilities:

Distance/Intensity Table

Time Period	*Meteorological Visibility Statute Miles*	*Distance Statute Miles*	*Intensity Candelas*
Night		2.9 (4.7km)	1,500 (+/- 25%)
	3 (4.8km)	3.1 (4.9km)	2,000 (+/- 25%)
		1.4 (2.2km)	32
Day		1.5 (2.4km)	200,000
	1 (1.6km)	1.4 (2.2km)	100,000
		1.0 (1.6km)	20,000 (+/- 25%)
Day		3.0 (4.8km)	200,000
	3 (4.8km)	2.7 (4.3km)	100,000
		1.8 (2.9km)	20,000 (+/- 25%)
Twilight	1 (1.6km)	1.0 (1.6km) to 1.5 (2.4km)	20,000 (+/- 25%)?
Twilight	3 (4.8km)	1.8 (2.9km) to 4.2 (6.7km)	20,000 (+/- 25%)?

Note-
1. DISTANCE CALCULATED FOR NORTH SKY ILLUMINANCE.

TBL 5

3. CONCLUSION.

Pilots of aircraft travelling at 165 knots (190 mph/306kph) or less should be able to see obstruction lights in sufficient time to avoid the structure by at least 2,000 feet (610m) horizontally under all conditions of operation, provided the pilot is operating in accordance with FAR Part 91. Pilots operating between 165 knots (190 mph/303 km/h) and 250 knots (288 mph/463 kph) should be able to see the obstruction lights unless the weather deteriorates to 3 statute miles (4.8 kilometers) visibility at night, during which time period 2,000 candelas would be required to see the lights at 1.2 statute miles (1.9km). A higher intensity, with 3 statute miles (4.8 kilometers) visibility at night, could generate a residential annoyance factor. In addition, aircraft in these speed ranges can normally be expected to operate under instrument flight rules (IFR) at night when the visibility is 1 statute mile (1.6 kilometers).

4. DEFINITIONS.

a. Flight Visibility. The average forward horizontal distance, from the cockpit of an aircraft in flight, at which prominent unlighted objects may be seen and identified by day and prominent lighted objects may be seen and identified by night.

Reference-
AIRMAN'S INFORMATION MANUAL
PILOT/CONTROLLER GLOSSARY.

b. Meteorological Visibility. A term that denotes the greatest distance, expressed in statute miles, that selected objects (visibility markers) or lights of moderate intensity (25 candelas) can be seen and identified under specified conditions of observation.

5. LIGHTING SYSTEM CONFIGURATION.

a. *Configuration A.* Red lighting system.

b. *Configuration B.* High Intensity White Obstruction Lights (including appurtenance lighting).

c. *Configuration C.* Dual Lighting System - High Intensity White & Red (including appurtenance lighting).

d. *Configuration D.* Medium Intensity White Lights (including appurtenance lighting).

e. *Configuration E.* Dual Lighting Systems - Medium Intensity White & Red (including appurtenance lighting).

Example-
"CONFIGURATION B 3" DENOTES A HIGH INTENSITY LIGHTING SYSTEM WITH THREE LEVELS OF LIGHT.

Coal Combustion: Nuclear Resource or Danger

By Alex Gabbard

Alex Gabbard at the coal pile for ORNL's steam plant.

Over the past few decades, the American public has become increasingly wary of nuclear power because of concern about radiation releases from normal plant operations, plant accidents, and nuclear waste. Except for Chernobyl and other nuclear accidents, releases have been found to be almost undetectable in comparison with natural background radiation. Another concern has been the cost of producing electricity at nuclear plants. It has increased largely for two reasons: compliance with stringent government regulations that restrict releases of radioactive substances from nuclear facilities into the environment and construction delays as a result of public opposition.

Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations

Partly because of these concerns about radioactivity and the cost of containing it, the American public and electric utilities have preferred coal combustion as a power source. Today 52% of the capacity for generating electricity in the United States is fueled by coal, compared with 14.8% for nuclear energy. Although there are economic justifications for this preference, it is surprising for two reasons. First, coal combustion produces carbon dioxide and other greenhouse gases that are suspected to cause climatic warming, and it is a source of sulfur oxides and nitrogen oxides, which are harmful to human health and may be largely responsible for acid rain. Second, although not as well known, releases from coal combustion contain naturally occurring radioactive materials--mainly, uranium and thorium.

Former ORNL researchers J. P. McBride, R. E. Moore, J. P. Witherspoon, and R. E. Blanco made this point in their article "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants" in the December 8, 1978, issue of Science magazine. They concluded that Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations. This ironic situation remains true today and is addressed in this article.

The fact that coal-fired power plants throughout the world are the major sources of radioactive materials released to the environment has several implications. It suggests that coal combustion is more hazardous to health than nuclear power and that it adds to the background radiation burden even more than does nuclear power. It also suggests that if radiation emissions from coal plants were regulated, their capital and operating costs would increase, making coal-fired power less economically competitive.

Finally, radioactive elements released in coal ash and exhaust produced by coal combustion contain fissionable fuels and much larger quantities of fertile materials that can be bred into fuels by absorption of neutrons, including those generated in the air by bombardment of oxygen, nitrogen, and other nuclei with cosmic rays; such fissionable and fertile materials can be recovered from coal ash using known technologies. These nuclear materials have growing value to private concerns and governments that may want to market them for fueling nuclear power plants. However, they are also available to those interested in accumulating material for nuclear weapons. A solution to this potential problem may be to encourage electric utilities to process coal ash and use new trapping technologies on coal combustion exhaust to isolate and collect valuable metals, such as iron and aluminum, and available nuclear fuels.

Makeup of Coal and Ash

Coal is one of the most impure of fuels. Its impurities range from trace quantities of many metals, including uranium and thorium, to much larger quantities of aluminum and iron to still larger quantities of impurities such as sulfur. Products of coal combustion include the oxides of carbon, nitrogen, and sulfur; carcinogenic and mutagenic substances; and recoverable minerals of commercial value, including nuclear fuels naturally occurring in coal.

The amount of thorium contained in coal is about 2.5 times greater than the amount of uranium

Coal ash is composed primarily of oxides of silicon, aluminum, iron, calcium, magnesium, titanium, sodium, potassium, arsenic, mercury, and sulfur plus small quantities of uranium and thorium. Fly ash is primarily composed of non-combustible silicon compounds (glass) melted during combustion. Tiny glass spheres form the bulk of the fly ash.

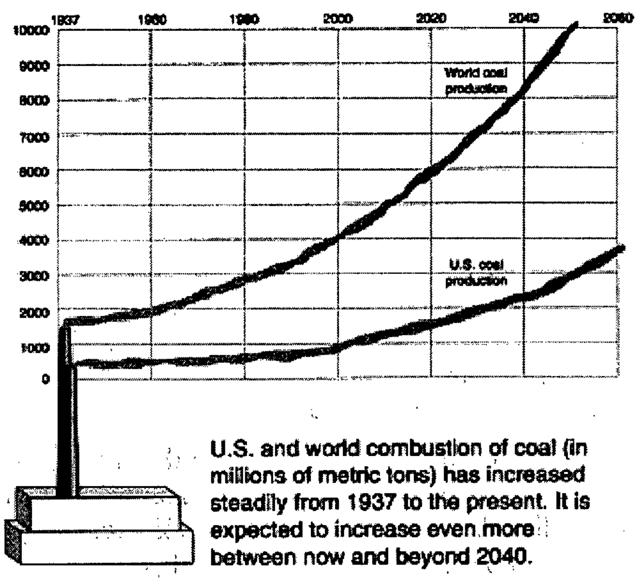
Since the 1960s particulate precipitators have been used by U.S. coal-fired power plants to retain significant amounts of fly ash rather than letting it escape to the atmosphere. When functioning properly, these precipitators are approximately 99.5% efficient. Utilities also collect furnace ash, cinders, and slag, which are kept in cinder piles or deposited in ash ponds on coal-plant sites along with the captured fly ash.

Trace quantities of uranium in coal range from less than 1 part per million (ppm) in some samples to around 10 ppm in others. Generally, the amount of thorium contained in coal is about 2.5 times greater than the amount of uranium. For a large number of coal samples, according to Environmental Protection Agency figures released in 1984, average values of uranium and thorium content have been determined to be 1.3 ppm and 3.2 ppm, respectively. Using these values along with reported consumption and projected consumption of coal by utilities provides a means of calculating the amounts of potentially recoverable breedable and fissionable elements (see sidebar). The concentration of fissionable uranium-235 (the current fuel for nuclear power plants) has been established to be 0.71% of uranium content.

Uranium and Thorium in Coal and Coal Ash

As population increases worldwide, coal combustion continues to be the dominant fuel source for electricity. Fossil fuels' share has decreased from 76.5% in 1970 to 66.3% in 1990, while nuclear energy's share in the worldwide electricity pie has climbed from 1.6% in 1970 to 17.4% in 1990. Although U.S. population growth is slower than worldwide growth, per capita consumption of energy in this country is among the world's highest. To meet the growing demand for electricity, the U.S. utility industry has continually expanded generating capacity. Thirty years ago, nuclear power appeared to be a viable replacement for fossil power, but today it represents less than 15% of U.S. generating capacity. However, as a result of low public support during recent decades and a reduction in the rate of expected power demand, no increase in nuclear power generation is expected in the foreseeable future. As current nuclear power plants age, many plants may be retired during the first quarter of the 21st century, although some may have their operation extended through license renewal. As a result, many nuclear plants are likely to be replaced with coal-fired plants unless it is considered feasible to replace them with fuel sources such as natural gas and solar energy.

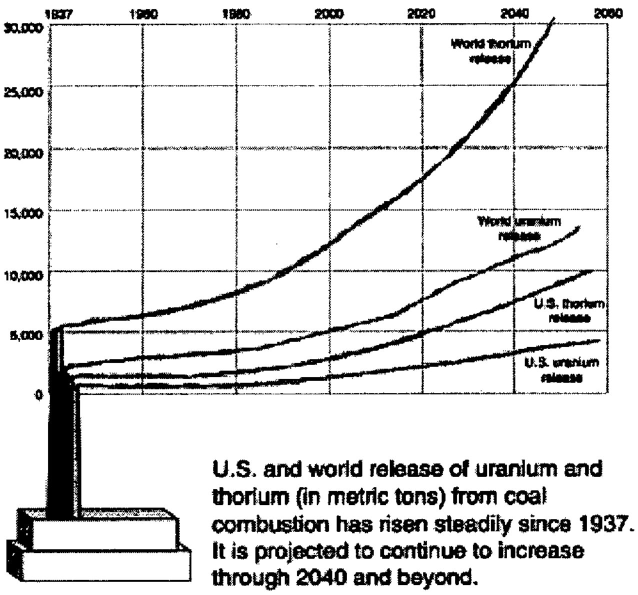
U.S. AND WORLD COAL COMBUSTION (millions of tons)



U.S. and world combustion of coal (in millions of metric tons) has increased steadily from 1937 to the present. It is expected to increase even more between now and beyond 2040.

As the world's population increases, the demands for all resources, particularly fuel for electricity, is expected to increase. To meet the demand for electric power, the world population is expected to rely increasingly on combustion of fossil fuels, primarily coal. The world has about 1500 years of known coal resources at the current use rate. The graph above shows the growth in U.S. and world coal combustion for the 50 years preceding 1988, along with projections beyond the year 2040. Using the concentration of uranium and thorium indicated above, the graph below illustrates the historical release quantities of these elements and the releases that can be expected during the first half of the next century, given the predicted growth trends. Using these data, both U.S. and worldwide fissionable uranium-235 and fertile nuclear material releases from coal combustion can be calculated.

U.S. AND WORLD RELEASE OF URANIUM AND THORIUM



U.S. and world release of uranium and thorium (in metric tons) from coal combustion has risen steadily since 1937. It is projected to continue to increase through 2040 and beyond.

Because existing coal-fired power plants vary in size and electrical output, to calculate the annual coal consumption of these facilities, assume that the typical plant has an electrical output of 1000 megawatts. Existing coal-fired plants of this capacity annually burn about 4 million tons of coal each year. Further, considering that in 1982 about 616 million short tons (2000 pounds per ton) of coal was burned in the United States (from 833 million short tons mined, or 74%), the number of typical coal-fired plants necessary to consume this quantity of coal is 154.

Using these data, the releases of radioactive materials per typical plant can be calculated for any year. For the year 1982, assuming coal contains uranium and thorium concentrations of 1.3 ppm and 3.2 ppm, respectively, each typical plant released 5.2 tons of uranium (containing 74 pounds of uranium-235) and 12.8 tons of thorium that year. Total U.S. releases in 1982 (from 154 typical plants) amounted to 801 tons of uranium (containing 11,371 pounds of uranium-235) and 1971 tons of thorium. These figures account for only 74% of releases from combustion of coal from all sources. Releases in 1982 from worldwide combustion of 2800 million tons of coal totaled 3640 tons of uranium (containing 51,700 pounds of uranium-235) and 8960 tons of thorium.

Based on the predicted combustion of 2516 million tons of coal in the United States and 12,580 million tons worldwide during the year 2040, cumulative releases for the 100 years of coal combustion following 1937 are predicted to be:

U.S. release (from combustion of 111,716 million tons):

Uranium: 145,230 tons (containing 1031 tons of uranium-235)

Thorium: 357,491 tons

Worldwide release (from combustion of 637,409 million tons):

Uranium: 828,632 tons (containing 5883 tons of uranium-235)

Thorium: 2,039,709 tons

Radioactivity from Coal Combustion

The main sources of radiation released from coal combustion include not only uranium and thorium but also daughter products produced by the decay of these isotopes, such as radium, radon, polonium, bismuth, and lead. Although not a decay product, naturally occurring radioactive potassium-40 is also a significant contributor.

The population effective dose equivalent from coal plants is 100 times that from nuclear plants

According to the National Council on Radiation Protection and Measurements (NCRP), the average radioactivity per short ton of coal is 17,100 millicuries/4,000,000 tons, or 0.00427 millicuries/ton. This figure can be used to calculate the average expected radioactivity release from coal combustion. For 1982 the total release of radioactivity from 154 typical coal plants in the United States was, therefore, 2,630,230 millicuries.

Thus, by combining U.S. coal combustion from 1937 (440 million tons) through 1987 (661 million tons) with an estimated total in the year 2040 (2516 million tons), the total expected U.S. radioactivity release to the environment by 2040 can be determined. That total comes from the expected combustion of 111,716 million tons of coal with the release of 477,027,320 millicuries in the United States. Global releases of radioactivity from the predicted combustion of 637,409 million tons of coal would be 2,721,736,430 millicuries.

For comparison, according to NCRP Reports No. 92 and No. 95, population exposure from operation of 1000-MWe nuclear and coal-fired power plants amounts to 490 person-rem/year for coal plants and 4.8 person-rem/year for nuclear plants. Thus, the population effective dose equivalent from coal plants is 100 times that from nuclear plants. For the complete nuclear fuel cycle, from mining to reactor operation to waste disposal, the radiation dose is cited as 136 person-rem/year; the equivalent dose for coal use, from mining to power plant operation to waste disposal, is not listed in this report and is probably unknown.

During combustion, the volume of coal is reduced by over 85%, which increases the concentration of the metals originally in the coal. Although significant quantities of ash are retained by precipitators, heavy metals such as uranium tend to concentrate on the tiny glass spheres that make up the bulk of fly ash. This uranium is released to the atmosphere with the escaping fly ash, at about 1.0% of the original amount, according to NCRP data. The retained ash is enriched in uranium several times over the original uranium concentration in the coal because the uranium, and thorium, content is not decreased as the volume of coal is reduced.

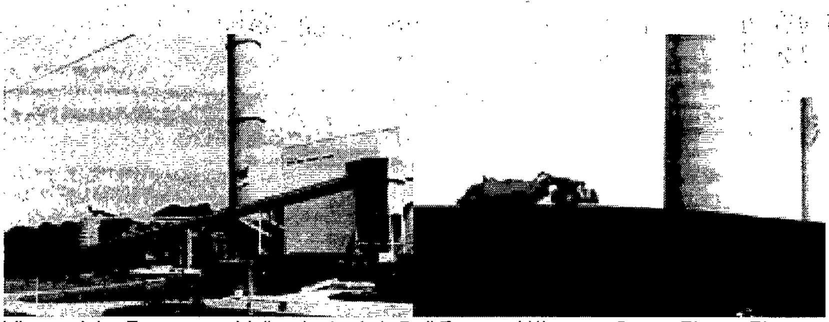
All studies of potential health hazards associated with the release of radioactive elements from coal combustion conclude that the perturbation of natural background dose levels is almost negligible. However, because the half-lives of radioactive potassium-40, uranium, and thorium are practically infinite in terms of human lifetimes, the accumulation of these species in the biosphere is directly proportional to the length of time that a quantity of coal is burned.

Although trace quantities of radioactive heavy metals are not nearly as likely to produce adverse health effects as the vast array of chemical by-products from coal combustion, the accumulated quantities of these isotopes over 150 or 250 years could pose a significant future ecological burden and potentially produce adverse health effects, especially if they are locally accumulated. Because coal is predicted to be the primary energy source for electric power production in the foreseeable future, the potential impact of long-term accumulation of by-products in the biosphere should be considered.

The energy content of nuclear fuel released in coal combustion is greater than that of the coal consumed

Energy Content: Coal vs Nuclear

An average value for the thermal energy of coal is approximately 6150 kilowatt-hours(kWh)/ton. Thus, the expected cumulative thermal energy release from U.S. coal combustion over this period totals about 6.87 x 10E14 kilowatt-hours. The thermal energy released in nuclear fission produces about 2 x 10E9 kWh/ton. Consequently, the thermal energy from fission of uranium-235 released in coal combustion amounts to 2.1 x 10E12 kWh. If uranium-238 is bred to plutonium-239, using these data and assuming a "use factor" of 10%, the thermal energy from fission of this isotope alone constitutes about 2.9 x 10E14 kWh, or about half the anticipated energy of all the utility coal burned in this country through the year 2040. If the thorium-232 is bred to uranium-233 and fissioned with a similar "use factor", the thermal energy capacity of this isotope is approximately 7.2 x 10E14 kWh, or 105% of the thermal energy released from U.S. coal combustion for a century. Assuming 10% usage, the total of the thermal energy capacities from each of these three fissionable isotopes is about 10.1 x 10E14 kWh, 1.5 times more than the total from coal. World combustion of coal has the same ratio, similarly indicating that coal combustion wastes more energy than it produces.



Views of the Tennessee Valley Authority's Bull Run and Kingston Steam Plants. These coal-fired facilities generate electricity for Oak Ridge and the surrounding area.

Consequently, the energy content of nuclear fuel released in coal combustion is more than that of the coal consumed! Clearly, coal-fired power plants are not only generating electricity but are also releasing nuclear fuels whose commercial value for electricity production by nuclear power plants is over $7 trillion, more than the U.S. national debt. This figure is based on current nuclear utility fuel costs of 7 mils per kWh, which is about half the cost for coal. Consequently, significant quantities of nuclear materials are being treated as coal waste, which might become the cleanup nightmare of the future, and their value is hardly recognized at all.

How does the amount of nuclear material released by coal combustion compare to the amount consumed as fuel by the U.S. nuclear power industry? According to 1982 figures, 111 American nuclear plants consumed about 540 tons of nuclear fuel, generating almost 1.1 x 10E12 kWh of electricity. During the same year, about 801 tons of uranium alone were released from American coal-fired plants. Add 1971 tons of thorium, and the release of nuclear components from coal combustion far exceeds the entire U.S. consumption of nuclear fuels. The same conclusion applies for worldwide nuclear fuel and coal combustion.

Another unrecognized problem is the gradual production of plutonium-239 through the exposure of uranium-238 in coal waste to neutrons from the air. These neutrons are produced primarily by bombardment of oxygen and nitrogen nuclei in the atmosphere by cosmic rays and from spontaneous fission of natural isotopes in soil. Because plutonium-239 is reportedly toxic in minute quantities, this process, however slow, is potentially worrisome. The radiotoxicity of plutonium-239 is 3.4 x 10E11 times that of uranium-238. Consequently, for 801 tons of uranium released in 1982, only 2.2 milligrams of plutonium-239 bred by natural processes, if those processes exist, is necessary to double the radiotoxicity estimated to be released into the biosphere that year. Only 0.075 times that amount in plutonium-240 doubles the radiotoxicity. Natural processes to produce both plutonium-239 and plutonium-240 appear to exist.

Conclusions

For the 100 years following 1937, U.S. and world use of coal as a heat source for electric power generation will result in the distribution of a variety of radioactive elements into the environment. This prospect raises several questions about the risks and benefits of coal combustion, the leading source of electricity production.

First, the potential health effects of released naturally occurring radioactive elements are a long-term issue that has not been fully addressed. Even with improved efficiency in retaining stack emissions, the removal of coal from its shielding overburden in the earth and subsequent combustion releases large quantities of radioactive materials to the surface of the earth. The emissions by coal-fired power plants of greenhouse gases, a vast array of chemical by-products, and naturally occurring radioactive elements make coal much less desirable as an energy source than is generally accepted.

Second, coal ash is rich in minerals, including large quantities of aluminum and iron. These and other products of commercial value have not been exploited.

Third, large quantities of uranium and thorium and other radioactive species in coal ash are not being treated as radioactive waste. These products emit low-level radiation, but because of regulatory differences, coal-fired power plants are allowed to release quantities of radioactive material that would provoke enormous public outcry if such amounts were released from nuclear facilities. Nuclear waste products from coal combustion are allowed to be dispersed throughout the biosphere in an unregulated manner. Collected nuclear wastes that accumulate on electric utility sites are not protected from weathering, thus exposing people to increasing quantities of radioactive isotopes through air and water movement and the food chain.

Fourth, by collecting the uranium residue from coal combustion, significant quantities of fissionable material can be accumulated. In a few year's time, the recovery of the uranium-235 released by coal combustion from a typical utility anywhere in the world could provide the equivalent of several World War II-type uranium-fueled weapons. Consequently, fissionable nuclear fuel is available to any country that either buys coal from outside sources or has its own reserves. The material is potentially employable as weapon fuel by any organization so inclined. Although technically complex, purification and enrichment technologies can provide high-purity, weapons-grade uranium-235. Fortunately, even though the technology is well known, the enrichment of uranium is an expensive and time-consuming process.

Because electric utilities are not high-profile facilities, collection and processing of coal ash for recovery of minerals, including uranium for weapons or reactor fuel, can proceed without attracting outside attention, concern, or intervention. Any country with coal-fired plants could collect combustion by-products and amass sufficient nuclear weapons material to build up a very powerful arsenal, if it has or develops the technology to do so. Of far greater potential are the much larger quantities of thorium-232 and uranium-238 from coal combustion that can be used to breed fissionable isotopes. Chemical separation and purification of uranium-233 from thorium and plutonium-239 from uranium require far less effort than enrichment of isotopes. Only small fractions of these fertile elements in coal combustion residue are needed for clandestine breeding of fissionable fuels and weapons material by those nations that have nuclear reactor technology and the inclination to carry out this difficult task.

Fifth, the fact that large quantities of uranium and thorium are released from coal-fired plants without restriction raises a paradoxical question. Considering that the U.S. nuclear power industry has been required to invest in expensive measures to greatly reduce releases of radioactivity from nuclear fuel and fission products to the environment, should coal-fired power plants be allowed to do so without constraints?

If increased regulation of nuclear power plants is demanded, then we can expect a significant redirection of national policy in regulation of radioactive emissions from coal combustion

This question has significant economic repercussions. Today nuclear power plants are not as economical to construct as coal-fired plants, largely because of the high cost of complying with regulations to restrict emissions of radioactivity. If coal-fired power plants were regulated in a similar manner, the added cost of handling nuclear waste from coal combustion would be significant and would, perhaps, make it difficult for coal-burning plants to compete economically with nuclear power.

Because of increasing public concern about nuclear power and radioactivity in the environment, reduction of releases of nuclear materials from all sources has become a national priority known as "as low as reasonably achievable" (ALARA). If increased regulation of nuclear power plants is demanded, can we expect a significant redirection of national policy so that radioactive emissions from coal combustion are also regulated?

Although adverse health effects from increased natural background radioactivity may seem unlikely for the near term, long-term accumulation of radioactive materials from continued worldwide combustion of coal could pose serious health hazards. Because coal combustion is projected to increase throughout the world during the next century, the increasing accumulation of coal combustion by-products, including radioactive components, should be discussed in the formulation of energy policy and plans for future energy use.

One potential solution is improved technology for trapping the exhaust (gaseous emissions up the stack) from coal combustion. If and when such technology is developed, electric utilities may then be able both to recover useful elements, such as nuclear fuels, iron, and aluminum, and to trap greenhouse gas emissions. Encouraging utilities to enter mineral markets that have been previously unavailable may or may not be desirable, but doing so appears to have the potential of expanding their economic base, thus offsetting some portion of their operating costs, which ultimately could reduce consumer costs for electricity.

Both the benefits and hazards of coal combustion are more far-reaching than are generally recognized. Technologies exist to remove, store, and generate energy from the radioactive isotopes released to the environment by coal combustion. When considering the nuclear consequences of coal combustion, policymakers should look at the data and recognize that the amount of uranium-235 alone dispersed by coal combustion is the equivalent of dozens of nuclear reactor fuel loadings. They should also recognize that the nuclear fuel potential of the fertile isotopes of thorium-232 and uranium-238, which can be converted in reactors to fissionable elements by breeding, yields a virtually unlimited source of nuclear energy that is frequently overlooked as a natural resource.

The amount of uranium-235 alone dispersed by coal combustion is the equivalent of dozens of nuclear reactor fuel loadings

In short, naturally occurring radioactive species released by coal combustion are accumulating in the environment along with minerals such as mercury, arsenic, silicon, calcium, chlorine, and lead, sodium, as well as metals such as aluminum, iron, lead, magnesium, titanium, boron, chromium, and others that are continually dispersed in millions of tons of coal combustion by-products. The potential benefits and threats of these released materials will someday be of such significance that they should not now be ignored.--*Alex Gabbard of the Metals and Ceramics Division*

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Wind Farm Area Calculator

This calculator estimates land-area requirements for wind power systems. The results indicate a "footprint" of land that has to be taken out of production to provide space for turbine towers, roads, and support structures.

The "footprint," which is typically between 0.25 and 0.50 acres per turbine, does not include the 5-10 turbine diameters of spacing required between wind turbines. Because of this spacing, the area included within the perimeter of the wind farm will be larger. However, it is important to note that the land between the turbines – minus the "footprint" area – is still usable for its original purpose.

Input Value	1000	(kW)
Area per turbine	0.38	(Acres)
Size of turbine	500	(kW)

submit

The estimated land area required is: **0.76 acres**.
This calculation assumes **1,000 kW** and **2 turbines** each requiring an area of **0.38 acres**.
Note: This value represents the area taken out of production on a farm.
The area within the perimeter of the wind farm will be larger due to spacing
of the turbines, but is still useable by the farm.
Typical turbine spacing in wind farms is placing the towers 5 to

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10
turbine diameters apart,
depending on local conditions.

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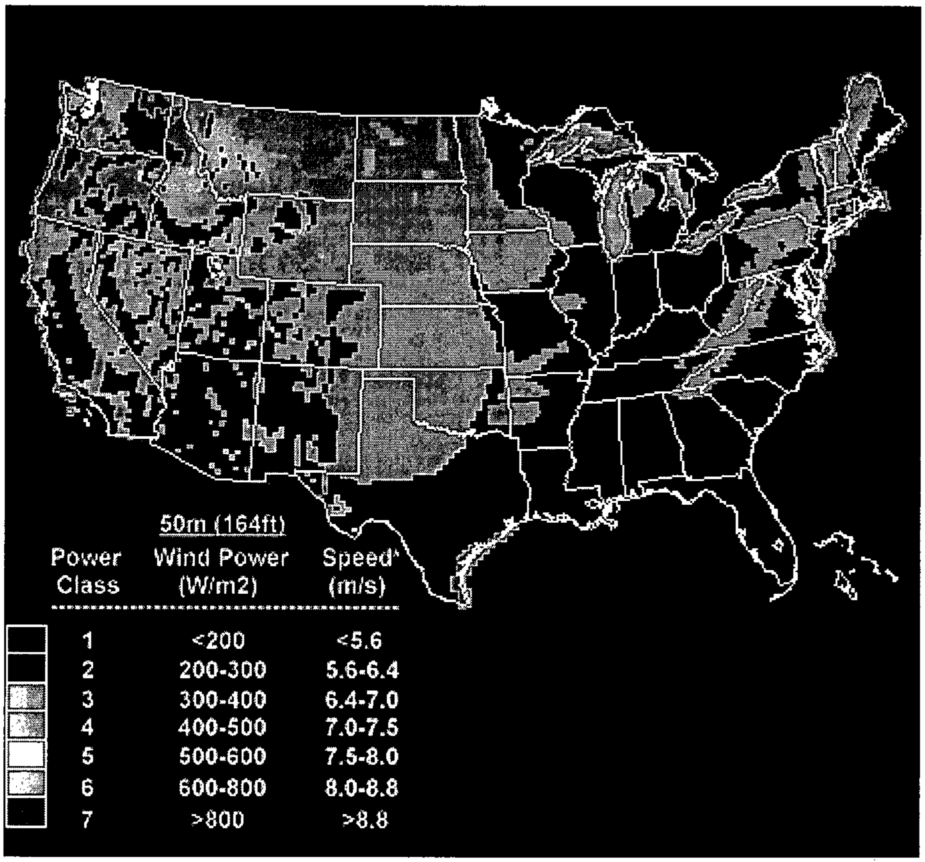
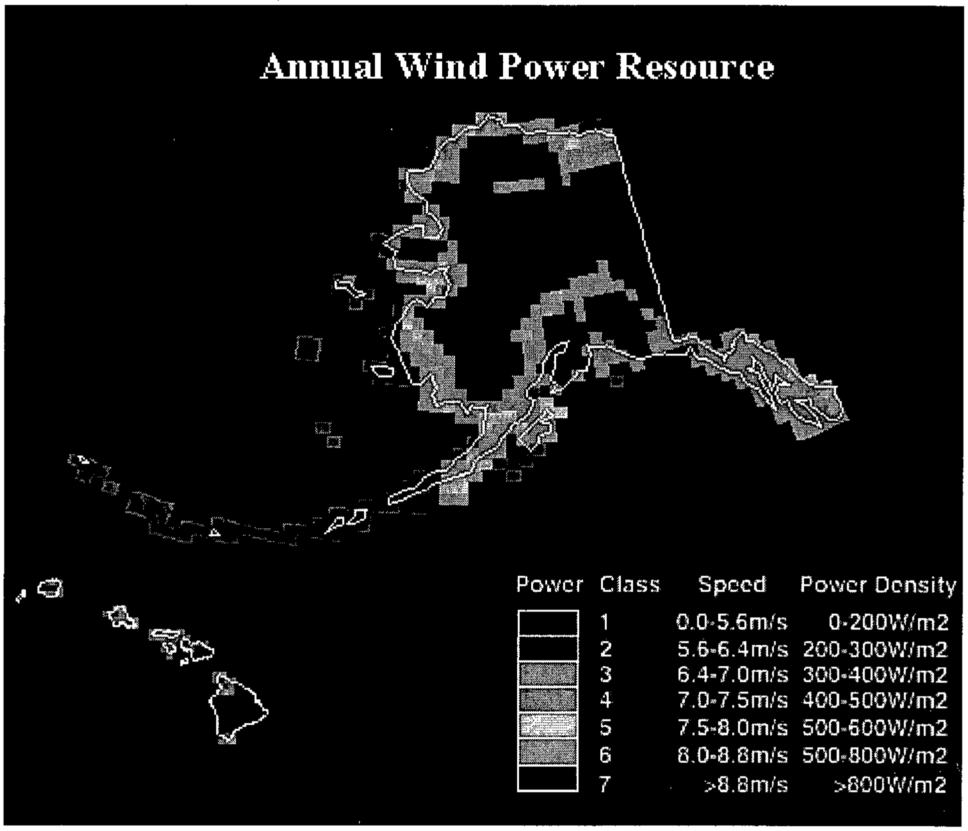
Wind Energy Resource Potential

Good wind areas, which cover 6% of the contiguous U.S. land area, have the potential to supply more than one and a half times the current electricity consumption of the United States.

Estimates of the wind resource are expressed in wind power classes ranging from class 1 to class 7, with each class representing a range of mean wind power density or equivalent mean speed at specified heights above the ground. Areas designated class 4 or greater are suitable with advanced wind turbine technology under development today. Power class 3 areas may be suitable for future technology. Class 2 areas are marginal and class 1 areas are unsuitable for wind energy development.

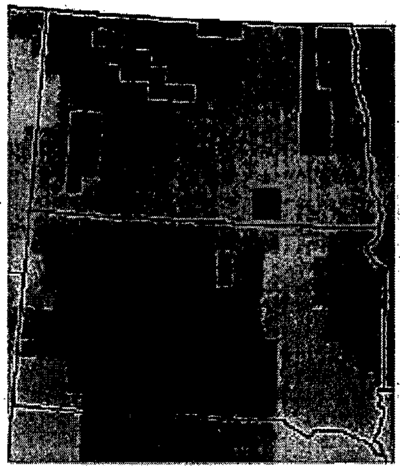


U.S. Annual Wind Power Resource and Wind Power Classes - Contiguous U.S. States.



U.S. Annual Wind Power Resource and Wind Power Classes - Alaska and Hawaii.

Because techniques of wind resource assessment have improved greatly in recent years, work began in 2000 to update the U.S. wind atlas. The work will produce regional-scale maps of the wind resource with resolution dowr to one square kilometer. The new atlas will take advantage of modern techniques for mapping. It will also incorporate new meteorological, geographical, and terrain data. The program's advanced mapping of the wind resource is another important element necessary for expanding wind-generating capacity in the United States.



1987

2000

1987 U.S. Wind Atlas Map vs. 2000 High-Resolution (1-km^2) Wind Map of North and South Dakota

Visit the Wind Powering America State Wind Map page to see if your state or area of interest has a newer, more detailed map available.

If you have difficulty accessing the information on this page because of a disability, please contact the webmaster for assistance.

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Vermont Wind Activities

This Web page summarizes completed/implemented Wind Powering America activities in Vermont, which include a wind working group, anemometer loan program, wind maps, a small wind consumer's guide, and state workshops. This page also highlights other wind activities for the state. Some of the following documents are available as Adobe Acrobat PDFs. Download Adobe Reader.

Wind Powering America Activities	
Wind Working Group	Not Currently
Anemometer Loan Program	YES
Validated Wind Map	YES
Small Wind Consumer's Guide	YES
Events	Not Currently
Past Events (2)	YES

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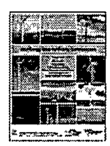

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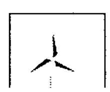

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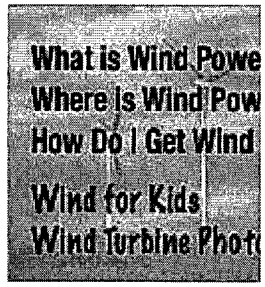

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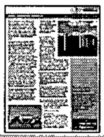
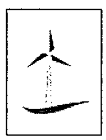
4/1/2000	VT			Vermont Activities Factsheet	...more
	VT			Wind Energy Planning Resources for Utility-Scale Systems in Vermont	...more
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Alternative Energy Resources in Vermont

Below is a short summary of alternative energy resources for Vermont. For more information on each technology, visit the State Energy Alternatives Technology Options page.

For more information, including links to resource maps, energy statistics, and contacts for Vermont, visit EERE's State Activities and Partnerships Web site's Vermont page.

Biomass

Studies indicate that Vermont has good biomass resource potential. For more state-specific resource information, see Biomass Feedstock Availability in the United States: 1999 State Level Analysis.

Geothermal

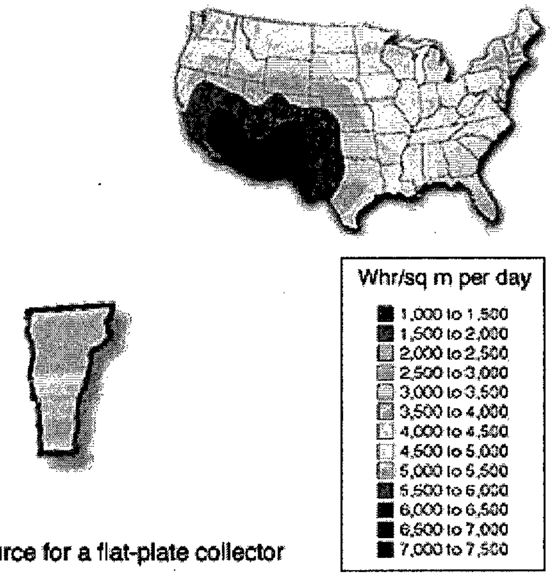
Vermont has vast low-temperature resources suitable for geothermal heat pumps. However, Vermont does not have sufficient resources to use the other geothermal technologies.

Hydropower

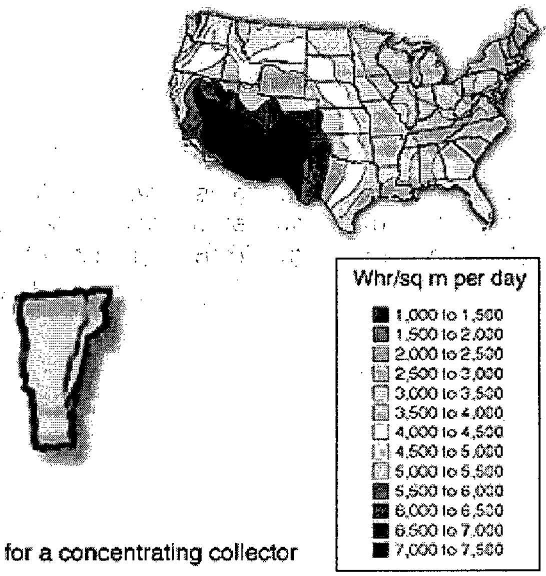
Vermont has a good hydropower resource as a percentage of the state's electricity generation. For additional resource information, check out the Idaho National Laboratory's Virtual Hydropower Prospector (VHP). VHP is a convenient geographic information system (GIS) tool designed to assist you in locating and assessing natural stream water energy resources in the United States.

Solar

To accurately portray your state's solar resource, we need two maps. That is because different collector types use the sun in different ways. Collectors that focus the sun (like a magnifying glass) can reach high temperatures and efficiencies. These are called concentrating collectors.



Solar resource for a flat-plate collector



Solar resource for a concentrating collector

Typically, these collectors are on a tracker, so they always face the sun directly. Because these collectors focus the sun's rays, they only use the direct rays coming straight from the sun.

Other solar collectors are simply flat panels that can be mounted on a roof or on the ground. Called flat-plate collectors, these are typically fixed in a tilted position correlated to the latitude of the location. This allows the collector to best capture the sun. These collectors can use both the direct rays from the sun and reflected light that comes through a cloud or off the ground. Because they use all available sunlight, flat-plate collectors are the best choice for many northern states. Therefore, this site gives you two maps: one is the resource for a concentrating collector and one is the resource for a flat-plate collector.

What does the map mean? Mainly, it means that, for flat-plate collectors, Vermont has useful resources throughout the state. The map shows that, for concentrating collectors, Vermont mostly has a relatively poor resource. In the eastern edge of the state, certain technologies might be applicable, but most concentrating collectors are not effective with this resource.

Wind

Wind Powering America indicates that Vermont has wind resources consistent with utility-scale production. The excellent wind resource areas in the state are on the ridge crests. In addition, small wind turbines may have applications in some areas. For more information on wind resources in Vermont including wind maps, visit Wind Powering America's State Wind Activities.

The Vermont Department of Public Service commissioned a study titled, *Estimating the Hypothetical Wind Power Potential on Public Lands in Vermont* (PDF 1.9 MB) (Download Adobe Reader) to determine the technical potential for wind power in the state. The State of Vermont commissioned a study to determine the technical potential for wind power in the state. From a resource availability estimate of all wind speeds, the methodology excluded the following areas:

- Areas of less than class 4 wind.
- Private or sensitive land.
- Areas not within 7 kilometers (km) (4.35 miles) of transmission lines.

On the remaining land larger than 2 kilometer square parcels, the methodology assumed specific turbine types in strings along ridgelines and determined the percentage of windy land likely to be compatible with wind development as shown in Table 1.

Table 1. Percentage of Windy Land Likely to Be Compatible with Wind Development

Wind Class	Wind Power Density, W/m^2	Speed, m/s (mph)	Land area (% of VT)	Federal (% of VT)	State (% of VT)	Municipal (% of VT)
<1		Insignificant	55.7	1.1	2.5	0.4
1	160	5.1 (11.4)	30.1	1.1	3.3	0.1
2	240	5.9 (13.2)	8.7	3.6	1.8	0.2
3	320	6.5 (14.6)	2.6	1.1	0.4	0.03
4	400	7.0 (15.7)	1.2	0.2	0.4	0

5	480	7.4 (16.6)	1.2	0.2	0.1	0.004
6	640	8.2 (18.3)	0.5	0.04	0.01	0
7	1600	11.0 (24.7)	0.002	0	0	0
Total:			100%	7.30%	8.50%	0.70%

Source: *Estimating the Hypothetical Wind Power Potential on Public Lands in Vermont*, 2003.

Energy Efficiency

Energy efficiency means doing the same work, or more, and enjoying the same comfort level with less energy. Consequently, energy efficiency can be considered part of your state's energy resource base - a demand side resource. Unlike energy conservation, which is rooted in behavior, energy efficiency is technology-based. This means the savings may be predicted by engineering calculations, and they are sustained over time. Examples of energy efficiency measures and equipment include compact fluorescent light bulbs (CFLs), and high efficiency air conditioners, refrigerators, boilers, and chillers.

Saving energy through efficiency is less expensive than building new power plants. Utilities can plan for, invest in, and add up technology-based energy efficiency measures and, as a consequence, defer or avoid the need to build a new power plant. In this way, Austin, Texas, aggregated enough energy savings to offset the need for a planned 450-megawatt coal-fired power plant. Austin achieved these savings during a decade when the local economy grew by 46% and the population doubled. In addition, the savings from energy efficiency are significantly greater than one might expect, because no energy is needed to generate, transmit, distribute, and store energy before it reaches the end user.

Reduced fuel use, and the resulting decreased pollution, provide short- and long-term economic and health benefits.

For more information on current state policies related to energy efficiency, visit the Alliance to Save Energy's State Energy Efficiency Index.

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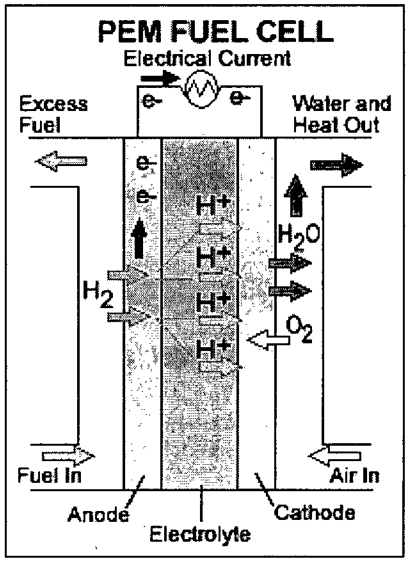
Types of Fuel Cells

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. Learn more about:

Polymer Electrolyte Membrane (PEM) Fuel Cells

Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers.

Polymer electrolyte membrane fuel cells operate at relatively low



temperatures, around 80°C (176°F). Low temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to CO poisoning, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO.

PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

A significant barrier to using these fuel cells in vehicles is hydrogen storage. Most fuel cell vehicles (FCVs) powered by pure hydrogen must store the hydrogen onboard as a compressed gas in pressurized tanks. Due to the low energy density of hydrogen, it is difficult to store enough hydrogen onboard to allow vehicles to travel the same distance as gasoline-powered vehicles before refueling, typically 300-400 miles. Higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline can be used for fuel, but the vehicles must have an onboard fuel processor to reform the methanol to hydrogen. This increases costs and maintenance requirements. The reformer also releases carbon dioxide (a greenhouse gas), though less than that emitted from current gasoline-powered engines.

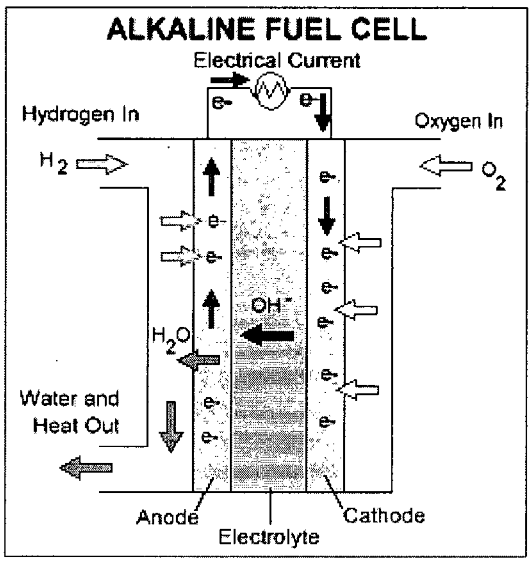
Direct Methanol Fuel Cells

Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. Direct methanol fuel cells (DMFCs), however, are powered by pure methanol, which is mixed with steam and fed directly to the fuel cell anode.

Direct methanol fuel cells do not have many of the fuel storage problems typical of some fuel cells since methanol has a higher energy density than hydrogen—though less than gasoline or diesel fuel. Methanol is also easier to transport and supply to the public using our current infrastructure since it is a liquid, like gasoline.

Direct methanol fuel cell technology is relatively new compared to that of fuel cells powered by pure hydrogen, and DMFC research and development are roughly 3-4 years behind that for other fuel cell types.

Alkaline Fuel Cells



Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water onboard spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. High-temperature AFCs operate at temperatures between 100°C and 250°C (212°F and 482°F). However, newer AFC designs operate at lower temperatures of roughly 23°C to 70°C (74°F to 158°F)

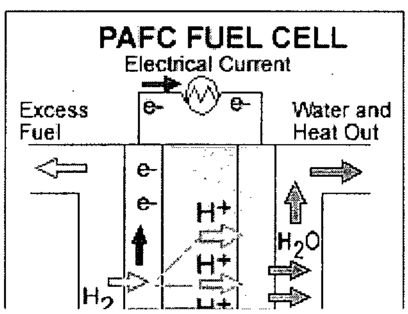
AFCs' high performance is due to the rate at which chemical reactions take place in the cell. They have also demonstrated efficiencies near 60 percent in space applications.

The disadvantage of this fuel cell type is that it is easily poisoned by carbon dioxide (CO_2). In fact, even the small amount of CO_2 in the air can affect this cell's operation, making it necessary to purify both the hydrogen and oxygen used in the cell. This purification process is costly. Susceptibility to poisoning also affects the cell's lifetime (the amount of time before it must be replaced), further adding to cost.

Cost is less of a factor for remote locations such as space or under the sea. However, to effectively compete in most mainstream commercial markets, these fuel cells will have to become more cost-effective. AFC stacks have been shown to maintain sufficiently stable operation for more than 8,000 operating hours. To be economically viable in large-scale utility applications, these fuel cells need to reach operating times exceeding 40,000 hours, something that has not yet been achieved due to material durability issues. This is possibly the most significant obstacle in commercializing this fuel cell technology.

Phosphoric Acid Fuel Cells

Phosphoric acid fuel cells use liquid phosphoric acid as an



electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The chemical reactions that take place in the cell are shown in the diagram to the right.

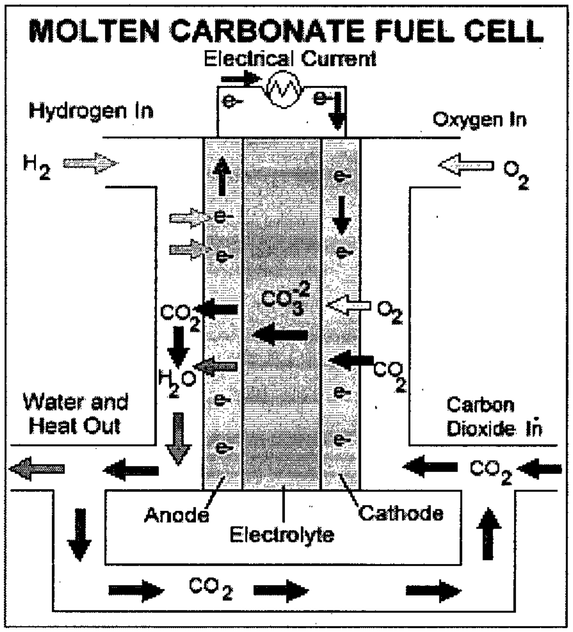
The phosphoric acid fuel cell (PAFC) is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells, which are easily "poisoned" by carbon monoxide—carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. They are 85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell. A typical phosphoric acid fuel cell costs between $4,000 and $4,500 per kilowatt to operate.

Molten Carbonate Fuel Cells

Molten
carbonate
fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide ($LiAlO_2$) matrix. Since they operate at extremely high temperatures of 650° C (roughly 1,200°F) and above, non-precious metals can be used as catalysts at the anode and cathode, reducing costs.

Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric



acid fuel cells (PAFCs). Molten carbonate fuel cells can reach efficiencies approaching 60 percent, considerably higher than the 37-42 percent efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be as high as 85 percent.

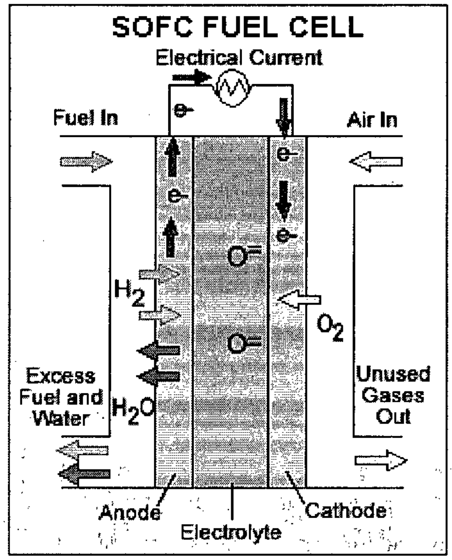
Unlike alkaline, phosphoric acid, and polymer electrolyte membrane fuel cells, MCFCs don't require an external reformer to convert more energy-dense fuels to hydrogen. Due to the high temperatures at which MCFCs operate, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost.

Molten carbonate fuel cells are not prone to carbon monoxide or carbon dioxide "poisoning" —they can even use carbon oxides as fuel— making them more attractive for fueling with gases made from coal. Because they are more resistant to impurities than other fuel cell types, scientists believe that they could even be capable of internal reforming of coal, assuming they can be made resistant to impurities such as sulfur and particulates that result from converting coal, a dirtier fossil fuel source than many others, into hydrogen.

The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that increase cell life without decreasing performance.

Solid Oxide Fuel Cells

Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the



electrolyte. Since the electrolyte is a solid, the cells do not have to be constructed in the plate-like configuration typical of other fuel cell types. SOFCs are expected to be around 50-60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 80-85 percent.

Solid oxide fuel cells operate at very high temperatures—around 1,000°C (1,830°F). High temperature operation removes the need for precious-metal catalyst, thereby reducing cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system.

SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types. In addition, they are not poisoned by carbon monoxide (CO), which can even be used as fuel. This allows SOFCs to use gases made from coal.

High-temperature operation has disadvantages. It results in a slow startup and requires significant thermal shielding to retain heat and protect personnel, which may be acceptable for utility applications but not for transportation and small portable applications. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology.

Scientists are currently exploring the potential for developing lower-temperature SOFCs operating at or below 800°C that have fewer durability problems and cost less. Lower-temperature SOFCs produce less electrical power, however, and stack materials that will function in this lower temperature range have not been identified.

Regenerative Fuel Cells

Regenerative fuel cells produce electricity from hydrogen and oxygen and generate heat and water as byproducts, just like other fuel cells. However, regenerative fuel cell systems can also use electricity from solar power or some other source to divide the excess water into oxygen and hydrogen fuel—this process is called "electrolysis." This is a comparatively young fuel cell technology being developed by NASA and others.

Comparison of Fuel Cell Technologies

Each fuel cell technology has advantages and disadvantages. See how fuel cell technologies compare with each other.

- Comparison Chart (PDF 123 KB) Download Adobe Reader.

Printable Version

Content Last Updated: 08/18/2006

SECA

NETL

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

SECA FAQs

q: What is a fuel cell?

a: A fuel cell is an electrochemical energy conversion device that uses a carbon and/or hydrogen fuel source and air to produce electrical power.

q: What fuels can fuel cells use?

a: Solid oxide fuel cells can use virtually any fuel: coal gas, hydrogen, bio-fuel, gasoline, diesel, JP8, or propane.

q: How do fuel cells improve the environment?

a: Fuel cells are virtually emissions free and quiet. Featuring significantly improved efficiency in comparison to conventional natural gas- or coal-combustion based power generation, greenhouse gas emissions are reduced.

SECA R&D: *Where Competition Meets Collaboration*

From New York to California, SECA's Core Technology Program is working on dozens of fuel cell projects, led by the brightest minds from leading universities, national laboratories and businesses across the country. These competitively selected projects work together to provide vital R&D and testing support to the six Industry Teams.

In the same spirit of healthy competition, the Industry Teams leverage the collective ingenuity of the Core Technology Program to independently pursue innovations in fuel cell design that can be mass produced at lower costs. Whether focused upon Cost Reduction or Coal-Based Systems, the Industry Teams are working to solve the challenges of fuel cell technology, each using different approaches and techniques. As a result, the SECA program is rich in innovation, allowing it to reach its goals that much faster.

SECA Cost Reduction: *The Power of a Goal*

The SECA program's Industry Teams are hard at work on the design and manufacture of a variety of low-cost fuel cell prototypes. Recent testing of these prototypes has demonstrated giant leaps made toward fuel cell commercialization.

Manufactured with a scalable mass-production technique, these SOFC prototypes exceed all of SECA's Phase I targets for availability, efficiency, endurance, and production cost. The system's operational availability was 90 percent, over and above the SECA Phase I target of 80 percent. An efficiency of 41 percent was achieved in the 5.4 kilowatt (kW) system, surpassing the target of 35 percent.

This superior efficiency in a small size demonstrates the achievability of much higher efficiencies for larger systems. And, most significant of all, system cost was a low $746/kW.

	SECA 2005 Targets	Actuals
Cost	—	$746/kW
Efficiency	35 – 55%	41% LHV-DC
Degradation	4%/1000 hours	3.6%/1000 hours
Availability	80%	90%

These accomplishments represent a major breakthrough toward achieving SECA's goal of mass-producing a $400/kW SOFC power generation system by 2010. The prototype's cost approaches that of conventional stationary power, furthering the vision of an economy driven by pollution-free, low-cost fuel cells.

SECA Manufacturing: *Building the Future*

Technical challenges remain to be overcome. Fuel cell technology has traditionally been too costly for broad penetration into commercial markets. SECA is focused on driving costs down to achieve widespread use in the public marketplace. SECA is blending established manufacturing processes with state-of-the-art fuel cell technology advancements in order to leverage the advantages of economies of production (high-volume mass production) and scale.

The cost-reduction goal is to make the cost of fuel cell technology comparable to that of current stationary power systems—$400/kW—by 2010.

To achieve this, the SECA program has set aggressive targets for its private sector Industry Teams. Dividing the research and development into three phases, SECA has set escalating benchmarks for achieving breakthroughs in cost and efficiency—the keys to commercial viability.

The Department of Energy projects that SECA technology will save the United States more than $100 billion by 2025 through increased efficiency leading to lower fuel costs and meeting emissions and carbon sequestration requirements without expensive control equipment.

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energy innovation

Fuel Cells

Powering AMERICA

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clean energy security efficient affordable

SOLID STATE ENERGY CONVERSION ALLIANCE

SECA: *Demanding Progress*

The race is on. Momentum is building. Research teams all across America are making innovations that will change the future of electricity generation. With the successful completion of its first phase, the Solid State Energy Conversion Alliance (SECA) is one step closer to realizing its vision of cost effective, near-zero-emission fuel cell technology for commercial applications.

Launched in 2000, SECA is a collaboration between government, the private sector and the scientific community to develop modular, low-cost, fuel-flexible solid oxide fuel cell (SOFC) systems that can operate on coal gas, natural gas, bio-fuels, diesel and hydrogen. SECA's ultimate mission is to have its fuel-cell systems ready for FutureGen, the world's cleanest coal-fueled power plant.

SECA's fuel cell development will provide America with a virtually emissions-free, efficient, and affordable power generation technology that will improve our environment and reduce our dependence on foreign oil.

SECA has already surpassed its Phase I targets. By developing fuel cells to operate cost effectively on coal gas as well as natural gas, bio-fuels, diesel and hydrogen, it is building a bridge to the hydrogen economy while solving today's environmental, climate change and fuel availability issues. The once distant vision of using clean, low-cost fuel cell technology for everyday applications is now within reach.

SECA Targets: *Fuel Cell Performance and Cost*

	Cost Reduction Targets		
	2005	2008	2010
Power Rating	3 to 10 kW	3 to 10 kW	3 to 10 kW
Cost	—	—	$400/kW
Efficiency (LHV)	35 to 55%	40 to 60%	40 to 60%
	Coal-Based Fuel Cell System Targets		
	2005	2010	2015
Power Rating*	500 kW	2 MW	50 MW
Cost	—	$400/kW	$400/kW
Efficiency (HHV)**	45%	50%	50%

** Estimated cumulative capacity for three Industry Teams*
*** Coal plant efficiency*

Fuel cells convert the chemical energy of a fuel (hydrogen, coal gas, natural gas, diesel and bio-fuels) into electrical energy without combustion.

SECA Cost Reduction: Phase I | 2005 | Phase II | 2008 | Phase III | 2010

SECA Coal-Based Systems: Phase I | 2006 | Phase II | 2010 | Phase III | 2015

FutureGen: Construction | 2012 | Operation | 2015

- **2000** SECA is formed
- **2001** First SECA awards
- **2005** Phase I cost goal achieved
- **2010** SECA achieves cost target of $400/kW
- **2012** FutureGen operation begins
- **2015** SECA fuel cells (50 MW) operated 25,000 hours demonstrating ability to achieve 50% efficiency in converting coal to grid electric power

SECA Coal-Based Systems: *Meeting Our Nation's Energy Needs*

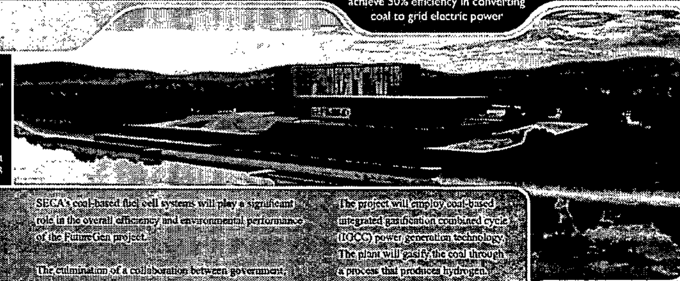
Coal is a critical resource for our future. There's plenty of it—the United States has 25 percent of the world's coal reserves, offering a substantial opportunity to reduce our dependence on foreign oil and natural gas markets. Coal currently provides more than half of the Nation's electricity supply. Coal provides a safe, secure, domestic source of affordable energy. The biggest question mark about coal—how to reduce its carbon dioxide emissions through higher efficiency and ease of capture—is being addressed by Fossil Energy R&D.

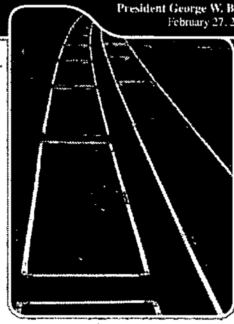
To address this challenge, SECA is developing large fuel cell systems to capitalize on the benefits of coal through clean and affordable central power station applications. SECA is ahead of schedule in developing fuel cell systems for FutureGen, the world's cleanest coal-based power plant, envisioned to render our most abundant and under-utilized resource virtually pollution-free.

FutureGen: *The Power Plant of Tomorrow*

"Today I am pleased to announce that the United States will sponsor a $1 billion, 10-year demonstration project to create the world's first coal-based, zero-emissions electricity and hydrogen power plant..."

President George W. Bush
February 27, 2003





Large near-zero-emission SOFC systems are 25% more efficient compared to conventional power generation.

SECA's coal-based fuel cell systems will play a significant role in the overall efficiency and environmental performance of the FutureGen project.

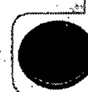
The culmination of a collaboration between government, the scientific community, and private industry, the $1 billion showcase FutureGen project is the first big step toward the President's goal of providing America with a secure energy future. FutureGen will demonstrate the efficient, clean and greenhouse gas free production of electricity and/or hydrogen from coal, and its viable commercial use in providing power to homes and businesses. When operational, it will be the cleanest fossil fuel-fired power plant in the world.

The project will employ coal-based integrated gasification combined cycle (IGCC) power generation technology. The plant will gasify the coal through a process that produces hydrogen. The hydrogen can then be used as a clean fuel for electricity generation in turbines or fuel cells, or a combination of the two. The process will capture and store 90 percent of carbon dioxide emissions preventing release as a greenhouse gas.

Competitive Innovation: *Accelerating Technology Development*

The Administration's Office of Management and Budget recently cited the SECA program as leading the way in Government-industry partnerships.

"The SECA program leverages private-sector ingenuity by providing Government funding to Industry Teams developing fuel cells, as long as the Teams continue to exceed a series of stringent technical performance hurdles. This novel incentive structure has generated a high level of competition between the Teams and an impressive array of technical approaches. The SECA program also develops certain core technologies that can be used by all the Industry Teams to avoid duplication of effort. The program exceeded its 2005 performance targets, and it is on track to meet its goal for an economically competitive technology by 2010."



a solid oxide fuel cell

a SOFC stack

What's Next

With Phase I cost reduction targets achieved, SECA will go full steam ahead into Phases II and III. It will reach the cost and coal-based systems performance targets by 2010 and deliver SECA fuel cells to the FutureGen project in 2011.

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SECA FAQs

q: Where are solid oxide fuel cells used?

a: Fuel cells can be used anywhere electric power is needed. Applications include providing power for homes and businesses from central- and distributed-power plants, as well as providing auxiliary power for buses, heavy duty trucks, military transports, RVs and more.

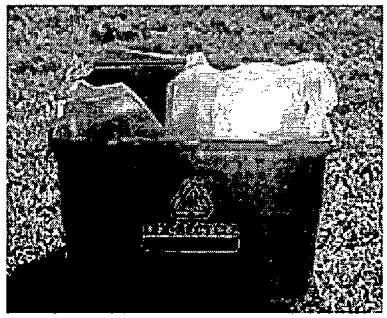
q: How efficient are fuel cells?

a: Fuel cells are much more efficient than today's conventional power generation technologies. For example, efficiency gains of 25% can be realized for central power plants that incorporate fuel cells within an integrated gasification combined cycle (IGCC) system.

q: How much do fuel cells cost?

a: The SECA fuel cell program will reduce the cost of fuel cells tenfold so that they can penetrate the power generation and transportation markets. SECA fuel cell technology will achieve its $400/kW target by 2010.

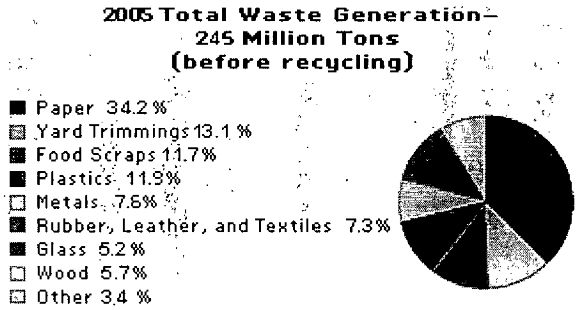
Basic Facts



Municipal Solid Waste (MSW)

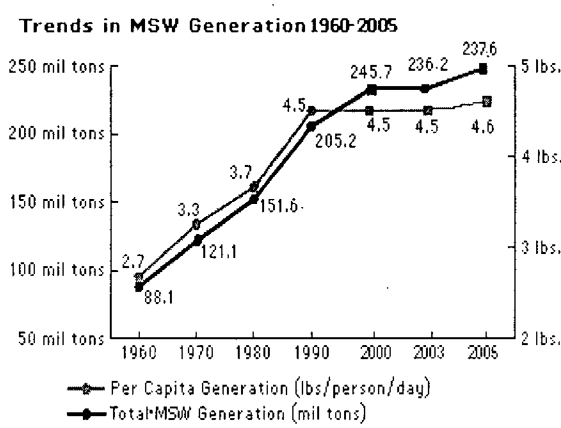
MSW—more commonly known as trash or garbage—consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. To learn more about MSW, view our interactive presentation about Milestones in Garbage: 1990–Present.

In 2005, U.S. residents, businesses, and institutions produced more than 245 million tonsof MSW, which is approximately 4.5 pounds of waste per person per day.



Several MSW management practices, such as source reduction, recycling, and composting, prevent or divert materials from the wastestream. Source reduction involves altering the design, manufacture, or use of products and materials to reduce the amount and toxicity of what gets thrown away. Recycling diverts items, such as paper, glass, plastic, and metals, from the wastestream. These materials are sorted, collected, and processed and then manufactured, sold, and bought as new products. Composting decomposes organic waste, such as food scraps and yard trimmings, with microorganisms (mainly bacteria and fungi), producing a humus-like substance.

Other practices address those materials that require disposal. Landfills are engineered areas where waste is placed into the land. Landfills usually have liner systems and other safeguards to prevent groundwater contamination. Combustion is another MSW practice that has helped reduce the amount of landfill space needed. Combustion facilities burn MSW at a high temperature, reducing waste volume and generating electricity.



Solid Waste Hierarchy

EPA has ranked the most environmentally sound strategies for MSW. Source reduction (including reuse) is the most preferred method, followed by recycling and composting, and, lastly, disposal in combustion facilities and landfills.

Currently, in the United States, 32 percent is recovered and recycled or composted, 14 percent is burned at combustion facilities, and the remaining 54 percent is disposed of in landfills.

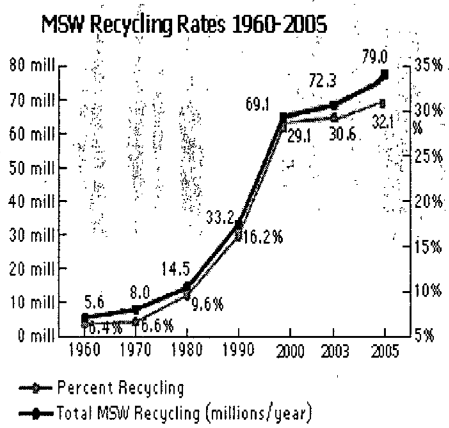
Source Reduction (Waste Prevention)

Source reduction can be a successful method of reducing waste generation. Practices such as grasscycling, backyard composting, two-sided copying of paper, and transport packaging reduction by industry have yielded substantial benefits through source reduction.

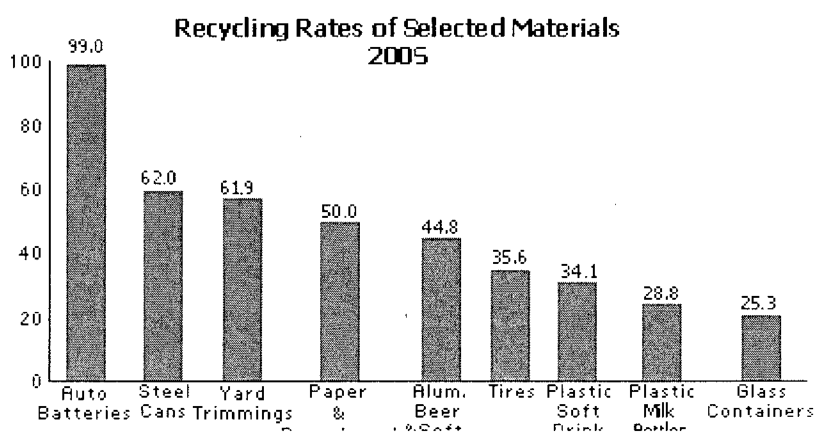
Source reduction has many environmental benefits. It prevents emissions of many greenhouse gases, reduces pollutants, saves energy, conserves resources, and reduces the need for new landfills and combustors.

Recycling

Recycling, including composting, diverted 79 million tons of material away from disposal in 2005, up from 15 million tons in 1980, when the recycle rate was just 10% and 90% of MSW was being combusted with energy recovery or disposed of by landfilling.



Typical materials that are recycled include batteries, recycled at a rate of 99%, paper and paperboard at 50%, and yard trimmings at 62%. These materials and others may be recycled through curbside programs, drop-off centers, buy-back programs, and deposit systems.



Recycling prevents the emission of many greenhouse gases and water pollutants, saves energy, supplies valuable raw materials to industry, creates jobs, stimulates the development of greener technologies, conserves resources for our children's future, and reduces the need for new landfills and combustors.

Recycling also helps reduce greenhouse gas emissions that affect global climate. In 1996, recycling of solid waste in the United States prevented the release of 33 million tons of carbon into the air-roughly the amount emitted annually by 25 million cars.

Combustion/Incineration

Burning MSW can generate energy while reducing the amount of waste by up to 90 percent in volume and 75 percent in weight.

EPA's Office of Air and Radiation is primarily responsible for regulating combustors because air emissions from combustion pose the greatest environmental concern.

In 2005, in the United States, there were 88 combustors with energy recovery with the capacity to burn up to 99,000 tons of MSW per day.

Landfills

Under the Resource Conservation and Recovery Act (RCRA), landfills that accept MSW are primarily regulated by state, tribal, and local governments. EPA, however, has established national standards these landfills must meet in order to stay open. Municipal landfills can, however, accept household hazardous waste.

The number of landfills in the United States is steadily decreasing—from 8,000 in 1988 to 1,654 in 2005. The capacity, however, has remained relatively constant. New landfills are much larger than in the past.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) was enacted by Congress in 1976 and amended in 1984. The act's primary goal is to protect human health and the environment from the potential hazards of waste disposal. In addition, RCRA calls for conservation of energy and natural resources, reduction in waste generated, and environmentally sound waste management practices.

Household Hazardous Waste

Households often discard many common items such as paint, cleaners, oils, batteries, and pesticides, that contain hazardous components. Leftover portions of these products are called household hazardous waste (HHW). These products, if mishandled, can be dangerous to your health and the environment.

Environmental Terms, Abbreviations, and Acronyms

EPA provides a glossary that defines in non-technical language commonly used environmental terms appearing in EPA publications and materials. It also explains abbreviations and acronyms used throughout EPA.

Recommended Sources for MSW Information

- *Municipal Solid Waste in the United States: 2005 Facts and Figures:* Describes the national MSW stream based on data collected between 1960 and 2003. Includes information on MSW generation, recovery, and discard quantities; per capita generation and discard rates; and residential and commercial portions of MSW generation.

- *Decision-Maker's Guide to Solid Waste Management, Volume II:* Contains technical and economic information to assist solid waste management practitioners in planning, managing, and operating MSW programs and facilities. Includes suggestions for best practices when planning or evaluating waste and recycling collection systems, source reduction and composting programs, public education, and landfill and combustion issues.

Additional MSW materials can be found at Publications.

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U.S. Environmental Protection Agency

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Controlling Power Plant Emissions: Overview

Controlling Power Plant Emissions

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- Decision Process & Chronology
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- Mercury NODA
- Clean Air Mercury Rule

On March 15, 2005, EPA issued the Clean Air Mercury Rule to permanently cap and reduce mercury emissions from coal-fired power plants for the first time ever. This rule, combined with EPA's Clean Air Interstate Rule (CAIR), will significantly reduce emissions from the nation's largest remaining source of human-caused mercury emissions.

Important progress on this issue began years ago. These pages cover this history; the proposed regulations to reduce mercury emissions in the power sector; the extensive comments received on these proposals; the process EPA pursued to best understand how to finalize these regulations, and information about existing and emerging technologies to reduce mercury emissions from power plants.

Together, the Clean Air Mercury Rule proposal and CAIR create a multi-pollutant strategy to improve air quality throughout the U.S. The landmark Clean Air Interstate Rule focuses on 28 eastern states having sulfur dioxide (SO 2) and nitrogen oxides (NOx) emissions that contribute significantly to fine particle and ozone pollution problems in downwind states.

President Bush's Clear Skies legislation would establish a mandatory program to reduce and cap emissions of mercury, as well as emissions of sulfur dioxide (SO 2) and nitrogen oxides (NOx) from electric power generation to approximately 70% below 2000 emission levels. Clear Skies was first submitted as proposed legislation in the US House of Representatives on July 26, 2002 and in the US Senate on July 28, 2002. The legislation was reintroduced in both Houses of Congress as the Clear Skies Act of 2003 on February 27, 2003, and in the Senate as the Clear Skies Act of 2005 on January 24, 2005. EPA continues to believe this legislative approach is the preferred option to achieve these important reductions; however, since the Congress has yet to act, the Agency issued CAIR and the Clean Air Mercury Rule to provide communities with tools to solve the problem of pollution transported from other states.

Chronology of Actions to Date

Since the Clean Air Act was amended in 1990, EPA has researched mercury, including how best to require reductions from power plants. This page provides a detailed chronology of events that led up to the proposal in January 2004, EPA's issuance of the final Clean Air Mercury Rule in March 2005, and of the reconsideration process that ended in May 2006.

Guiding Principles

Reducing mercury from power plants must be done right. The Agency took into account relevant information about emissions, control technologies, health effects, and the impacts on our electrical system and economic competitiveness. Given the complexity surrounding all of these factors, EPA identified five principles for providing context for additional inquiry and focus entering the decision phase of the rulemaking. This page describes these principles and areas of additional inquiry.

Applying Technology

Approximately 75 tons of mercury are found in the coal delivered to power plants each year and about two thirds of this mercury is emitted to the air, resulting in about 50 tons being emitted annually. This 25-ton reduction is achieved in the power plant boilers and through existing pollution controls such as fabric filters (for particulate matter), scrubbers (for SO 2) and SCRs (for NOx). As more scrubbers and SCRs are installed to comply with the Clean Air Interstate Rule and other regulations, mercury emissions are expected to decrease. This multipollutant approach is central to the Agency's plan to reduce mercury from power plants.

In addition to relying on existing technologies, several mercury-specific control technologies are in various stages of development, testing, and demonstration. Currently none of these technologies are in commercial operation on power plants in the U.S. but EPA expects these technologies to play a role as EPA and states require reductions in mercury emissions.

This page provides more information on technologies to reduce mercury from power plants.

Global Context

This page provides information about sources of mercury emissions throughout the world, the global distribution of emissions, and how U.S. mercury emissions fit into the global picture.

Public Comments

EPA received a record number of comments on its proposed mercury rule. This page provides a summary of the comment process and information for people interested in reviewing comments.

Where to find more information

Summary of the proposed Utility Mercury Reductions Rule - as well as a summary of the design of the program and the benefits it would provide.

Regulatory Actions - Links to proposed and final rules, fact sheets, and other rulemaking documents.

Technical Information - Technical support information and links to related information.

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NRC NEWS

U.S. NUCLEAR REGULATORY COMMISSION

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No. 01-035 M

NRC ORGANIZES FUTURE LICENSING PROJECT ORGANIZATION

NRC's Office of Nuclear Reactor Regulation intends to staff the organization in phases with the objective of hav functional Future Licensing Project Organization by the end of September.

Several utilities and organizations have contacted the NRC to initiate discussions associated with the possible c new nuclear power plants in the United States. These include Exelon's request for a pre-application review of a Modular Reactor and Exelon's stated intention to submit an application to build the Pebble Bed Reactor.

Licensees have also indicated to the NRC that applications for early site permits could be submitted in the near These permits would allow pre-certification of sites for possible construction of nuclear power plants. An applic design certification of the Westinghouse AP 1000, an advanced light water reactor incorporating "passive" safe also is expected next year. While the schedules for these activities are not certain, NRC is gearing up to carry (licensing responsibilities efficiently.

This first phase group will be responsible for establishing a project management function for future licensing ta include updating parts of NRC regulations, review of the AP 1000 reactor design, preparation for Pebble Bed re licensing review, coordination with NRC's Office of Nuclear Regulatory Research on Pebble Bed reactor pre-app issues, environmental and siting project management and other tasks, including interaction with interested sta The group will be formed initially through rotational assignment of staff experienced in regulatory programs, in design certification process.

Biomass Feedstock Availability in the United States: 1999 State Level Analysis

Marie E. Walsh[a], Robert L. Perlack[a], Anthony Turhollow[a], Daniel de la Torre Ugarte[b], Denny A. Becker[c], Robin L. Graham[a], Stephen E. Slinsky[b], and Daryll E. Ray[b]

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April 30, 1999, Updated January, 2000

I. Introduction

Interest in using biomass feedstocks to produce power, liquid fuels, and chemicals in the U.S. is increasing. Central to determining the potential for these industries to develop is an understanding of the location, quantities, and prices of biomass resources. This paper describes the methodology used to estimate biomass quantities and prices for each state in the continental U.S. An Excel™ spreadsheet contains estimates of biomass quantities potentially available in five categories: mill wastes, urban wastes, forest residues, agricultural residues and energy crops. Availabilities are sorted by anticipated delivered price. A presentation that explains how this information was used to support the goal of increasing biobased products and bioenergy 3 times by 2010 expressed in Executive Order 13134 of August 12, 1999 is also available.

II. Biomass Feedstock Availability

For the purpose of this analysis, biomass feedstocks are classified into five general categories: forest residues, mill residues, agricultural residues, urban wood wastes, and dedicated energy crops. Forestry is a major industry in the United States encompassing nearly 559 million acres in publicly and privately held forest lands in the continental U.S. (USDA, 1997). Nearly 16 million cubic feet of roundwood are harvested and processed annually to produce sawlogs, paper, veneers, composites and other fiber products (USDA, 1998a). The extensive forest acreage and roundwood harvest generate logging residues and provide the potential to harvest non-merchantable wood for energy. Processing of the wood into fiber products creates substantial quantities of mill residues that could potentially be used for energy. Agriculture is another major industry in the United States. Approximately 337 million acres of cropland are currently in agricultural production (USDA, 1997). Following the harvest of many of the traditional agricultural crops, residues (crop stalks) are left in the field. A portion of these residues could potentially be collected and used for energy. Alternatively, crop acres could be used to grow dedicated energy crops. A final category of biomass feedstocks includes urban wood wastes. These wastes include yard trimmings and other wood materials that are generally disposed of in municipal solid waste (MSW) and construction/demolition (C/D) landfills. Following is a description of the potential availability of these biomass feedstocks in the United States.

A. Forest Residues

Forest wood residues can be grouped into the following categories--logging residues; rough, rotten, and salvable dead wood; excess saplings; and small pole trees[(1)]. The forest wood residue supplies that could potentially be available for energy use in the U.S. are estimated using an updated version of a model originally developed by McQuillan et al. (1984). The McQuillan model estimates the total quantities of forest wood residues that can be recovered by first classifying the total forest inventory by the above wood categories (for both softwood and hardwood), and by volume, haul distances, and equipment operability constraints. This total inventory is then revised downward to reflect the quantities that can be recovered in each class due to constraints on equipment retrieval efficiencies, road access to a site, and impact of site slope on harvest equipment choice[(2)].

The costs of obtaining the recoverable forest wood residues are estimated for each category. Prices include collection, harvesting, chipping, loading, hauling, and unloading costs, a stumpage fee, and a return for profit and risk. Prices are in 1995 dollars. For the purposes of this analysis, we have included only logging residues and rough, rotten, and salvable dead wood quantities. The potential annual forest waste residues available by state for three price scenarios are presented in Table 1. Quantities are cumulative quantities at each price (i.e., quantities at $50/dt include all quantities available at $40/dt plus quantities available between $40 and $50/dt).

Polewood, which represent the growing stock of merchantable trees, has not been included in the analysis due to the fact that it could potentially be left to grow and used for higher value fiber products. It is doubtful that these trees will be harvested for energy use. However, if harvested, they could add another 17 million dry tons at less than $30/dt delivered; 37.7 million dry tons at less than $40 delivered; and 65 million dry tons at less than $50/dt delivered. For a more detailed explanation of the methodology used to estimate the forest wood residue quantities and prices, see Walsh et al, 1998.

Table 1: Estimated Annual Cumulative Forest Residues Quantities (dry tons), by Delivered Price and State

	< $30/dry ton delivered	< $40/dry ton delivered	< $50/dry ton delivered
Alabama	1009000	1475000	1899000
Arizona	134000	200000	261400
Arkansas	928000	1352000	1737800
California	1231000	1819000	2364400
Colorado	373000	554000	720300
Connecticut	109000	159000	204100
Delaware	26000	37000	48400
Florida	515000	755000	9757000
Georgia	1041000	1525000	1967800
Idaho	605000	902000	1179500
Illinois	228000	330000	423300
Indiana	253000	367000	470100

Iowa	72000	105000	135000
Kansas	47000	68000	88100
Kentucky	475000	690000	883500
Louisiana	872000	1275000	1641800
Maine	806000	1182000	1529100
Maryland	189000	273000	351200
Massachusetts	196000	284000	366200
Michigan	710000	1034000	1327900
Minnesota	468000	682000	874900
Mississippi	946000	1380000	1774600
Missouri	505000	733000	938700
Montana	676000	1007000	1316700
Nebraska	19000	27000	34400
Nevada	8000	11000	14400
New Hampshire	299000	438000	564400
New Jersey	70000	102000	130700
New Mexico	125000	185000	241900
New York	933000	1360000	1746400
North Carolina	1068000	1557000	2004900
North Dakota	11000	17000	21700
Ohio	232000	335000	430100
Oklahoma	156000	228000	292200
Oregon	1299000	1928000	2515900
Pennsylvania	948000	1377000	1763000
Rhode Island	20000	27000	35900
South Carolina	613000	898000	1158400
South Dakota	33000	49000	64300
Tennessee	930000	1351000	1732600
Texas	557000	814000	1050700
Utah	90000	133000	173000
Vermont	265000	386000	497200

Virginia	959000	1397000	1793600
Washington	1230000	1825000	2379600
West Virginia	727000	1056000	1352500
Wisconsin	609000	886000	1138400
Wyoming	132000	196000	256100
U.S. Total	23747000	34771000	44871800

B. Primary Mill Residues

The quantities of mill residues generated at primary wood mills (i.e., mills producing lumber, pulp, veneers, other composite wood fiber materials) in the U.S. are obtained from the data compiled by the USDA Forest Service for the 1997 Resource Policy Act (RPA) Assessment (USDA, 1998a). Mill residues are classified by type and include bark; coarse residues (chunks and slabs); and fine residues (shavings and sawdust). Data is available for quantities of residues generated by residue type and on uses of residues by residue type and use category (i.e., not used, fuel, pulp, composite wood materials, etc.). Data is available at the county, state, subregion, and regional level. In cases where a county has fewer than three mills, data from multiple counties are combined to maintain the confidentiality of the data provided by individual mills. Data represent short run average quantities.

Because primary mill residues are clean, concentrated at one source, and relatively homogeneous, nearly 98 percent of all residues generated in the United States are currently used as fuel or to produce other fiber products. Of the 24.2 million dry tons of bark produced in the U.S., 2.2 percent is not used while 79.4 percent is used for fuel and 18 percent is used for such things as mulch, bedding, and charcoal. Only about 1.4 percent of the 38.7 million dry tons of coarse residues are not used. The remainder are used to produce pulp or composite wood products such as particle board, wafer board, and oriented strand board (78 percent) and about 13 percent are used for fuel. Of the 27.5 million dry tons of fine wood residues, approximately 55.6 percent are used for fuel, 23 percent are used to produce pulp or composite wood products, 18.7 percent are used for bedding, mulch and other such uses, and about 2.6 percent are unused.

The residues, while currently used, could potentially be available for energy use if utilities could pay a higher price for the residues than their value in their current uses. Data regarding the value of these residues in their current uses are difficult to obtain. Much of the residues used for fuel are used on site by the residue generator in low efficiency boiler systems to produce heat and steam. Conversations with those in the industry and other anecdotal evidence suggests that these residues could be purchased for $15-25/dry ton for use in higher efficiency fuel systems. Similar anecdotal evidence suggests that residues used to produce fiber products (pulp, composite wood materials) sell for about $30-40/dry ton. For the purposes of this analysis, we assume that the residues not currently used could potentially be available for energy uses at delivered prices of less than $20/dry ton (assuming transportation distances of less than 50 miles). For similar transportation distances, we assume that residues currently used for fuel could be available at less than $30/dry ton delivered and residues currently used for pulp, composite wood materials, mulch, bedding, and other such uses could potentially be available at delivered prices of less than $50/dry ton. Table 2 presents the cumulative annual quantities of mill residues by delivered price for each state.

Table 2: Estimated Annual Cumulative Mill Residue Quantities (dry tons), by Delivered Price and State

	< $20/dry ton delivered	< $30/dry ton delivered	< $50/dry ton delivered
Alabama	17000	4581000	7802000
Arizona	0	75000	251000
Arkansas	2000	2497000	4705000
California	8000	2294000	4823000
Colorado	86000	121000	180000
Connecticut	0	40000	91000
Delaware	0	4000	16000
Florida	4000	1412000	2678000
Georgia	72000	3913000	7969000
Idaho	69000	1629000	4400000
Illinois	19000	117000	282000
Indiana	31000	213000	699000
Iowa	2000	46000	158000
Kansas	1000	9000	20000
Kentucky	109000	421000	1940000
Louisiana	64000	1943000	3245000
Maine	43000	209000	504000
Maryland	0	13000	166000
Massachusetts	0	44000	135000
Michigan	10000	932000	1564000
Minnesota	71000	916000	1121000
Mississippi	128000	3178000	6029000
Missouri	162000	315000	1196000
Montana	17000	659000	2173000
Nebraska	12000	21000	69000
Nevada	0	0	0
New Hampshire	23000	439000	1109000
New Jersey	0	8000	21000

New Mexico	25000	61000	125000
New York	28000	495000	1274000
North Carolina	33000	2060000	5028000
North Dakota	0	3000	4000
Ohio	0	0	0
Oklahoma	0	318000	698000
Oregon	10000	1738000	6834000
Pennsylvania	172000	591000	1628000
Rhode Island	0	11000	25000
South Carolina	4000	1706000	3382000
South Dakota	8000	46000	124000
Tennessee	202000	1325000	2018000
Texas	18000	1649000	4043000
Utah	20000	67000	102000
Vermont	0	59000	124000
Virginia	80000	1234000	2860000
Washington	5000	2262000	5689000
West Virginia	136000	459000	967000
Wisconsin	42000	1202000	192000
Wyoming	47000	124000	255000
U.S. Total	1780000	41459000	90418000

C. Agricultural Residues

Agriculture is a major activity in the United States. Among the most important crops in terms of average total acres planted from 1995 to 1997 are corn (77 million acres), wheat (72 million acres), soybeans (65 million acres), hay (60.5 million acres), cotton (15 million acres), grain sorghum (10 million acres), barley (7 million acres), oats (5 million acres), rice (3 million acres), and rye (1.5 million acres) (USDA, 1998b). After harvest, a portion of the stalks could potentially be collected for energy use. The analysis in this paper is limited to corn stover and wheat straw. Large acreage is dedicated to soybean production, but in general, residue production is relatively small and tends to deteriorate rapidly in the field, limiting the usefulness of soybean as an energy feedstock. However, additional residue quantities could be available from this source that have not been included in this analysis. Similarly, additional residue quantities could be available if barley, oats, rice, and rye production were included. Production of some of these crops (rice in particular) tends to be concentrated in a relatively small geographic area, and thus these crops could be an important local source of resources. Another potential source in the southern

U.S. is cotton. A recent study (NEOS, 1998) suggests that approximately 500,000 dry tons of cotton gin trash is currently produced in the United States and this material is generally given away to farmers for use as a soil amendment. Another 171,000 dry tons of textile mill residues are produced, but much of this material is used to make other textiles and sells for prices in excess of $100/dry ton. These quantities are not included in this analysis.

The quantities of corn stover and wheat straw residues that can be available in each state are estimated by first calculating the total quantities of residues produced and then calculating the total quantities that can be collected after taking into consideration quantities that must be left to maintain soil quality (i.e., maintain organic matter and prevent erosion). Residue quantities generated are estimated using grain yields, total grain production, and a ratio of residue quantity to grain yield,[(3)]

The net quantities of residue per acre that are available for collection are estimated by subtracting from the total residue quantity generated, the quantities of residues that must remain to maintain quality (Lightle, 1997). Quantities that must remain differ by crop type, soil type, typical weather conditions, and the tillage system used. A state average was used for this analysis. In general, about 30 to 40 percent of the residues can be collected.

The estimated prices of corn stover and wheat straw include the cost of collecting the residues, the premium paid to farmers to encourage participation, and transportation costs.

The cost of collecting the agricultural residues are estimated using an engineering approach. For each harvest operation, an equipment complement is defined. Using typical engineering specifications, the time per acre required to complete each operation and the cost per hour of using each piece of equipment is calculated (ASAE, 1995; NADA, 1995; USDA, 1996; Doanes, 1995). For corn stover, the analysis assumes 1x mow, 1x rake, 1x bale with a large round baler, and pickup, transport, and unloading of the bales at the side of the field where they are stored until transport to the user facility. The same operations are assumed for wheat straw minus the mowing. The operations assumed are conservative--mowing is often eliminated and the raking operation is also eliminated in some circumstances. The method used to estimate collection costs is consistent with that used by USDA to estimate the costs of producing agricultural crops (USDA, 1996).

An additional cost of $20/dry ton is added to account for the premium paid to farmers and the transportation cost from the site of production to the user facility. Currently, several companies purchase corn stover and/or wheat straw to produce bedding, insulating materials, particle board, paper, and chemicals (Gogerty, 1996). These firms typically pay $10 to $15/dry ton to farmers to compensate for any lost nutrient or environmental benefits that result from harvesting residues. The premium paid to farmers depends, in part, on transportation distance with farmers whose fields are at greater distances from the user facility receiving lower premiums. Studies have estimated that the cost of transporting giant round bales of switchgrass are $5 to $10 per dry ton for haul distances of less than 50 miles (Bhat et al, 1992; Graham et al, 1996; Noon et al, 1996). Agricultural residue bales are of similar size, weight, and density as switchgrass bales, and a similar transportation cost is assumed. This cost is similar to the reported transportation costs of facilities that utilize agricultural residues (Schechinger, 1997). Prices are in 1995$. For a more detailed explanation of the methodology used to estimate agricultural residue quantities and prices, see Walsh et al, 1998. The estimated annual cumulated agricultural residues quantities, by delivered price and state are contained in Table 3. Table 3 also contains by state, the percent of the total available residues that are corn stover.

Table 3: Estimated Annual Cumulative Agricultural Residue Quantities

(dry tons), by Delivered Price and State						
	< $30/dry ton delivered		< $40/dry ton delivered		< $50/dry ton delivered	
	Quantity	% Corn	Quantity	% Corn	Quantity	% Corn
Alabama	0	0	0	0	19267	0
Arizona	0	0	221864	24	221864	24
Arkansas	0	0	859361	0	984495	13
California	0	0	1478283	40	1478283	40
Colorado	0	0	2523820	90	2523820	90
Connecticut	0	0	0	0	0	0
Delaware	0	0	88077	0	300736	0
Florida	0	0	14824	0	14824	0
Georgia	0	0	344423	0	779871	56
Idaho	0	0	1248120	10	1248120	10
Illinois	0	0	24270757	94	24270757	94
Indiana	0	0	11883845	94	11883845	94
Iowa	0	0	23911214	99	23911214	99
Kansas	0	0	8570003	48	8570003	48
Kentucky	0	0	471819	0	2280603	49
Louisiana	0	0	80930	0	380557	79
Maine	0	0	0	0	0	0
Maryland	0	0	272468	0	802298	66
Massachusetts	0	0	0	0	0	6
Michigan	0	0	680783	0	4265671	84
Minnesota	0	0	11935896	88	11935896	88
Mississippi	0	0	0	0	37877	0
Missouri	0	0	1204353	0	4081358	70
Montana	0	0	406592	9	406592	9
Nebraska	0	0	16326915	98	16326915	98
Nevada	0	0	15350	0	15350	0
New Hampshire	0	0	0	0	0	0

New Jersey	0	0	32723	0	32723	0
New Mexico	0	0	476529	55	476529	55
New York	0	0	129515	0	129515	0
North Carolina	0	0	473229	0	1130744	58
North Dakota	0	0	14015	0	3715404	0
Ohio	0	0	7634476	82	7634476	82
Oklahoma	3214403	0	3440745	7	3440745	7
Oregon	0	0	155855	40	155855	40
Pennsylvania	0	0	197689	0	1031195	0
Rhode Island	0	0	0	0	0	0
South Carolina	0	0	239680	0	239680	0
South Dakota	0	0	3686246	71	2852740	71
Tennessee	0	0	300849	0	1004781	70
Texas	0	0	4497784	66	4497784	66
Utah	0	0	216546	29	216546	29
Vermont	0	0	0	0	0	0
Virginia	0	0	297986	0	585717	21
Washington	0	0	1364254	30	1364254	30
West Virginia	0	0	12008	0	51295	77
Wisconsin	0	0	5179618	97	5179618	97
Wyoming	0	0	171585	51	171585	51
U.S. Total	3214403	0	135331029	81	150651402	80

D. Dedicated Energy Crops

Dedicated energy crops include short rotation woody crops (SRWC) such as hybrid poplar and hybrid willow, and herbaceous crops such as switchgrass (SG). Currently, dedicated energy crops are not produced in the United States, but could be if they could be sold at a price that ensures the producer a profit at least as high as could be earned using the land for alternative uses such as producing traditional agricultural crops. The POLYSYS model is used to estimate the quantities of energy crops that could potentially be produced at various energy crop prices. POLYSYS is an agricultural sector model that includes all major agricultural crops (wheat, corn, soybeans, cotton, rice, grain sorghum, barley, oats, alfalfa, other hay crops); a livestock sector; and food, feed, industrial, and export demand functions. POLYSYS was developed and is maintained by the Agricultural Policy Analysis Center at the University of Tennessee and is used by the USDA Economic Research Service to conduct economic and policy analysis. Under a joint project between USDA and DOE, POLYSYS is being modified to include dedicated energy crops. A workshop consisting of USDA and DOE experts was held in November, 1997 to review the energy crop data being incorporated into the POLYSYS model.

The analysis includes cropland acres that are presently planted to traditional crops, idled, in pasture, or are in the Conservation Reserve Program. Energy crop production is limited to areas climatically suited for their production--states in the Rocky Mountain region and the Western Plains region are excluded. Because the CRP is an environmental program, two management scenarios have been evaluated--one to optimize for biomass yield and one to provide for high wildlife divesity. Energy crop yields vary within and between states, and are based on field trial data and expert opinion. Energy crop production costs are estimated using the same approach that is used by USDA to estimate the cost of producing conventional crops (USDA, 1996). Recommended management practices (planting density, fertilizer and chemical applications, rotation lengths) are assumed. Additionally, switchgrass stands are assumed to remain in production for 10 years before replanting, are harvested annually, and are delivered as large round bales. Hybrid poplars are planted at a 8 x 10 foot spacing (545 trees/acre) and are harvested in the 10th year of production in the northern U.S., after 8 years of production in the southern U.S., and after 6 years of production in the Pacific Northwest. Poplar harvest is by custom operation and the product is delivered as whole tree wood chips. Hybrid willow varieties are suitable for production in the northern U.S. The analysis assumes 6200 trees/acre, with first harvest in year 4 and subsequent harvests every three years for a total of 7 harvests before replanting is necessary. Willow is delivered as whole tree chips.

The estimated quantities of energy crops are those that could potentially be produced at a profit at least as great as could be earned producing traditional crops on the same acres, given the assumed energy crop yield and production costs, and the 1999 USDA baseline production costs, yields, and traditional crop prices (USDA, 1999b). In the U.S., switchgrass production dominates hybrid poplar and willow production at the equivalent (on an MBTU basis) market prices. The POLYSYS model estimates the farmgate price; an average transportation cost of $8/dt is added to determine the delivered price. Prices are in $1997. Table 4 presents the estimated annual cumulative quantities of energy crops by state by delivered price. For a more detailed explanation of the methodology used to estimate dedicated energy crop prices and quantities, see Walsh et al, 1998 and de la Torre Ugarte et al, 1999.

Table 4: Estimated Annual Cumulative Energy Crop Quantities (dry tons), by Delivered Price and State

	< $30/dry ton delivered	< $40/dry ton delivered	< $50/dry ton delivered
Alabama	0	3283747	6588812
Arizona	0	0	0
Arkansas	0	1709915	5509780
California	0	0	0
Colorado	0	0	0
Connecticut	0	0	199646
Delaware	0	0	31454
Florida	0	0	1268290

Georgia	0	1321438	3958181
Idaho	0	0	0
Illinois	0	1427349	7689694
Indiana	0	418042	5026234
Iowa	0	234292	8295486
Kansas	0	2859261	11438271
Kentucky	0	3598827	5128780
Louisiana	0	3923954	5813200
Maine	0	0	0
Maryland	0	0	298653
Massachusetts	0	0	235908
Michigan	0	1154228	4179308
Minnesota	0	427467	5783002
Mississippi	0	5330671	9304782
Missouri	0	5251442	12780923
Montana	0	0	2778386
Nebraska	0	1922058	5172860
Nevada	0	0	0
New Hampshire	0	0	158757
New Jersey	0	0	142902
New Mexico	0	0	0
New York	0	0	3388035
North Carolina	0	639228	1632077
North Dakota	0	1928463	16757889
Ohio	0	3808089	9657080
Oklahoma	0	3644173	8083722
Oregon	0	0	0
Pennsylvania	0	0	2338243
Rhode Island	0	0	4943
South Carolina	0	1338745	2438152
South Dakota	0	5613863	12757734

Tennessee	0	6616717	9350856
Texas	0	4549899	9139885
Utah	0	0	0
Vermont	0	0	333465
Virginia	0	1260668	2609867
Washington	0	0	0
West Virginia	0	269250	1190299
Wisconsin	0	3595636	6114270
Wyoming	0	0	487361
U.S. Total	0	66127422	188067187

E. Urban Wood Wastes

Urban wood wastes include yard trimmings, site clearing wastes, pallets, wood packaging, and other miscellaneous commercial and household wood wastes that are generally disposed of at municipal solid waste (MSW) landfills and demolition and construction wastes that are generally disposed of in construction/demolition (C/D) landfills. Data regarding quantities of these wood wastes is difficult to find and price information is even rarer. Additionally, definitions differ by states. Some states collect data on total wastes deposited at each MSW and C/D landfill in their states, and in some states, the quantities are further categorized by type (i.e., wood, paper and cardboard, plastics, etc.). However, not all states collect this data. Therefore, the quantities presented are crude estimates based on survey data (Glenn, 1998; Bush et al, 1997; Araman et al, 1997).

For municipal solid wastes (MSW) a survey by Glenn, 1998 is used to estimate total MSW generated by state. These quantities are adjusted slightly to correspond to regional MSW quantities that are land-filled as estimated by a survey conducted by Araman et al, 1997. Using the Araman survey, the total amount of wood contained in land-filled MSW is estimated. According to this survey, about 6 percent of municipal solid waste in the Midwest is wood, with 8 percent of the MSW being wood in the South, 6.6 percent being wood in the Northeast and 7.3 percent being wood in the West. Estimated quantities were in wet tons; they were corrected to dry tons by assuming a 15 percent moisture content by weight.

To estimate construction and demolition wastes (C/D), the Glenn study and the Bush et al, 1997 survey were used. The Glenn study provided the number of C/D landfills by state, and the Bush et al survey provided the average quantity of waste received per C/D landfill by region as well as the regional percent of the waste that was wood. According to the Bush et al survey, C/D landfills in the Midwest receive an average 25,700 tons of waste per year with 46 percent of that quantity being wood. In the South, C/D landfills receive an average 36,500 tons of waste/yr with 39 percent being wood. Northeastern C/D landfills receive an average 13,700 tons of waste/yr with 21 percent being wood and Western C/D landfills receive an average 28,800 tons of waste/yr with 18 percent being wood. Estimated quantities were in wet tons; they were corrected to dry tons by assuming a 15 percent moisture content by weight.

Yard trimmings taken directly to a compost facility rather than land-filled, were estimated from the Glenn study. This estimate was made by multiplying the number of compost facilities in each state by the national average tons of material received by site (2750 tons). The total compost material was then corrected for the percent that is yard trimmings (assumed to be 80 percent) and for the quantity that is wood (assumed to be 90 percent). Quantities were corrected to dry tons by assuming a 40 percent moisture by weight.

In an effort to reduce the quantities of waste materials that are land-filled, most states actively encourage the recycling of wastes. Quantities and prices of recycled wood wastes are not readily available. However, the Araman and Bush surveys report limited data on the recycling of wood wastes at MSW and C/D sites. They report that in the South, approximately 36 percent of C/D landfills and 50 percent of MSW landfills operate a wood/yard waste recycling facility and that about 34 percent of the wood at C/D landfills and 39 percent of the wood at MSW landfills is recycled. In the Midwest, about 31 percent of the MSW and 25 percent of the C/D landfills operate wood recycling facilities with 16 percent of the MSW wood and 1 percent of the C/D wood is recycled. In the West, 27 percent of the MSW and C/D landfills operate wood recycling facilities and recycle 25 percent each of their wood. In the Northeast, 39 percent of the MSW and 28 percent of the C/D landfills operate wood recycling facilities and recycle 39 percent of the MSW wood and 28 percent of the C/D wastes.

The surveys do not report the use of total recycled wood, but do report the uses of recycled pallets which represent about 7 percent of the total wood and 4 percent of the recycled wood at C/D landfills and about 24 percent of the total wood and about 13 percent of the recycled wood at MSW landfills. At C/D landfills, about 14 percent of the recycled pallets are re-used as pallets, about 39 percent are used as fuel, and the remainder is used for other purposes such as mulch and composting. About 69 percent of the recyclers reported that they gave away the pallet material. Of those selling the material, the mean sale price was $11.01/ton and the median sale price was $10.50/ton. At MSW landfills, about 3 percent of the recycled pallets are re-used as pallets, about 41 percent are used as fuel, and the remainder is used for other purposes such as mulch and composting. About 58 percent of the C/D recyclers reported that they gave away the pallet material. Of those selling the material, the mean sale price was $13.17/ton and the median sale price was $10.67/ton. Transportation costs must still be added to the sale price. Given the lack of information regarding prices, we assumed that of the total quantity available, 60 percent could be available at less than $20/dry ton and that the remaining quantities could be available at less than $30/dry ton. Table 5 presents the estimated annual cumulative quantities of urban wood wastes by state and price.

Table 5: Estimated Annual Cumulative Urban Wood Waste Quantities (dry tons), by Delivered Price and State

	< $20/dry ton	< $30/dry ton	< $40/dry ton	< $50/dry ton
Alabama	823566	1372610	1372610	1372610
Arizona	219736	366227	366227	366227
Arkansas	400364	667273	667273	667273
California	1579813	2633022	2633022	2633022
Colorado	94661	157769	157769	157769
Connecticut	246938	411563	411563	411563
Delaware	38959	64931	64931	64931
Florida	2757950	4596584	4596584	4596584
Georgia	862094	1436823	1436823	1436823

Idaho	135265	338162	338162	338162
Illinois	416047	693411	693411	693411
Indiana	316610	527684	527684	527684
Iowa	171802	286337	286337	286337
Kansas	736289	1227148	1227148	1227148
Kentucky	345699	576165	576165	576165
Louisiana	452322	753870	753870	753870
Maine	108358	180597	180597	180597
Maryland	204643	341071	341071	341071
Massachusetts	419272	698787	698787	698787
Michigan	495734	826224	826224	826224
Minnesota	919517	1532529	1532529	1532529
Mississippi	470831	784719	784719	784719
Missouri	315547	525911	525911	525911
Montana	52060	86766	86766	86766
Nebraska	102073	170121	170121	170121
Nevada	184112	306853	306853	306853
New Hampshire	110579	184298	184298	184298
New Jersey	389089	648481	648481	648481
New Mexico	142896	238160	238160	238160
New York	1140080	1900133	1900133	1900133
North Carolina	636035	1060056	1060056	1060056
North Dakota	326510	544184	544184	544184
Ohio	744518	1240864	1240864	1240864
Oklahoma	111173	185289	185289	185289
Oregon	182532	304220	304220	304220
Pennsylvania	399963	666605	666605	666605
Rhode Island	29803	49671	49671	49671
South Carolina	1289900	2149833	2149833	2149833
South Dakota	123982	206637	206637	206637
Tennessee	676029	1126715	1126715	1126715
Texas	1209449	2015749	2015749	2015749
Utah	138765	231275	231275	231275
Vermont	40802	68004	68004	68004
Virginia	519454	865757	865757	865757
Washington	292432	487387	487387	487387
West Virginia	105236	175393	175393	175393
Wisconsin	383466	639110	639110	639110

Wyoming	177383	295638	295638	295638
U.S. Total	22040338	36846616	36846616	36846616

III. Summary

Table 6 summarizes the estimated total annual cumulative quantities of biomass resources available by state and delivered price. It is estimated that substantial quantities of biomass (510 million dry tons) could be available annually at prices of less that $50/dt delivered. However, several caveats should be noted. There is a great deal of uncertainty surrounding some of the estimates. For example, while there is substantial confidence in the estimated quantities of mill residues available by state, there is a great deal of uncertainty about the estimated prices of these residues. The value of these feedstocks in their current uses is speculative and based solely on anecdotal discussions. Given that the feedstock is already being used--much of it under contract or in-house by the generator of the waste--energy facilities may need to pay a higher price than assumed to obtain the feedstock. Additionally, both the quantity and price of urban wastes are highly speculative. The analysis is based solely on one national study and regional averages taken from two additional surveys. There is no indication of the quality of the material present (i.e., whether the wood is contaminated with chemicals, etc.). Because of the ways in which the surveys were conducted, there may be double counting of some quantities (i.e., MSW may contain yard trimmings and C/D wastes as well). Additionally, the analysis assumes that the majority of this urban wood is available for a minimal fee, with much of the cost resulting from transportation. Other industries have discovered that once a market is established, these "waste materials" become more valuable and are no longer available at minimal price. This situation could also happen with urban wastes used for energy if a steady customer becomes available. It should also be noted however, that some studies indicate that greater quantities of urban wastes are available, and are available at lower prices, than are assumed in this analysis (Wiltsee, 1998). Given the high level of uncertainty surrounding the quantity and price estimates of urban wastes and mill residues, and the fact that these wastes are estimated to be the least cost feedstocks available, they should be viewed with caution until a more detailed analysis is completed.

The analysis has assumed that substantial quantities of dead forest wood could be harvested. The harvest of deadwood is a particularly dangerous activity and not one relished by most foresters. Additionally, large polewood trees represent the growing stock of trees, that if left for sufficient time, could be harvested for higher value uses. These opportunity costs have not been considered. And, the sustainability of removing these forest resources has not been thoroughly analyzed.

We estimate the price of agricultural residues to be high largely because of the small quantities that can be sustainably removed on a per acre basis. Improvements in the collection/transport technologies and the ability to sustainably collect larger quantities (due to a shift in no-till site preparation practices for example) could increase quantities and decrease prices over time. Also, the inclusion of some of the minor grain crops (i.e., barley, oats, rye, rice) and soybeans could increase the total quantities of agricultural residues available by state. However, further elucidation of quantities that can sustainably be removed might lower available quantities.

Dedicated energy crops (i.e., switchgrass and short rotation wood crops) are not currently produced--the analysis is based on our best estimates of yield, production costs, and profitability of alternative crops that could be produced on the same land. Improving yields and decreasing production costs through improved harvest and transport technologies could increase available quantities at lower costs.

We have assumed a transportation cost of $8/dry ton for most feedstocks. This cost is based on a typical cost of transporting materials (i.e., switchgrass bales and wood chips) for less than 50 miles (Graham et al, 1996; Bhat et al, 1992; Noon et al, 1996). Finally, the analysis is conducted at a state level and the distribution of biomass resources within the state is not specifically considered. We have simply assumed that the feedstock is available within 50 miles of a user facility. This may not be the case which would result either in the cost of the feedstock being higher to a user facility due to increased transportation costs, or the quantities of available feedstock being lower to a user facility if the material is simply too far away from the end-user site to be practical to obtain. Biomass resource assessments are needed at a lower aggregation level than the state. Any facility considering using the analysis need to conduct its own local analysis to verify feedstock quantity and prices.

Table 6: Estimated Cumulative Biomass Quantities (dry ton/yr), by Delivered Price and State

	< $20/dry ton	< $30/dry ton	< $40/dry ton	< $50/dry ton
Alabama	840566	6962610	10712357	17681689
Arizona	219736	575227	863091	1100491
Arkansas	402364	4092273	7085549	13604348
California	1587813	6158022	8224305	11298705
Colorado	180661	651769	3356589	3581889
Connecticut	246938	560563	610563	906309
Delaware	38959	94931	194008	461521
Florida	2761950	6753122	6778408	9533398
Georgia	934094	6390823	8540684	16111675
Idaho	204265	2572162	4117282	7165782
Illinois	435047	1038411	26838517	33359162
Indiana	347610	993684	13409571	18606863
Iowa	173802	404337	24582843	32786037
Kansas	737289	1283148	12733412	21343522
Kentucky	454699	1472165	5757811	10809048
Louisiana	516322	3568870	7976754	11834427
Maine	151358	1195597	1571597	2213697
Maryland	204643	543071	899539	1959222
Massachusetts	419272	938787	1026787	1435895
Michigan	505734	2468224	4627235	12163103
Minnesota	990517	2916529	15493892	21247327
Mississippi	598831	4908719	10673390	17930978

Missouri	477547	1345911	8029706	19522892
Montana	69060	1421766	2159358	6761444
Nebraska	114073	210121	18467094	21773296
Nevada	184112	314853	333203	336603
New Hampshire	133579	922298	1061298	2016455
New Jersey	389089	726481	791204	975806
New Mexico	167896	424160	960689	1081589
New York	1168080	3328133	3884648	8438083
North Carolina	669035	4188056	5789513	10855777
North Dakota	326510	558184	2506662	21043177
Ohio	744518	1472864	13018429	18962520
Oklahoma	111173	3873692	7816207	12699956
Oregon	192532	3341220	4126075	9809975
Pennsylvania	571963	2205605	2832294	7427043
Rhode Island	29803	80671	87671	115514
South Carolina	1293900	4468833	6332258	9368065
South Dakota	131982	285637	9601746	16005411
Tennessee	878029	3381715	10720281	15232952
Texas	1227449	4221749	13526432	20747118
Utah	158765	388275	647821	722821
Vermont	40802	392004	513004	1022669
Virginia	599454	3058757	5055411	8714941
Washington	297432	3979387	5938641	9920241
West Virginia	241236	1361393	1971651	3736487
Wisconsin	425466	2450110	11502364	14963398
Wyoming	224383	551638	787223	1465684
U.S. Total	23820338	105496557	314535067	510855005

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1. Logging residues are the unused portion of the growing of stock trees (i.e., commercial species with a diameter breast height (dbh) greater than 5 inches, excluding cull trees) that are cut or killed by logging and left behind. Rough trees are those that do not contain a sawlog (i.e., 50 percent or more of live cull volume) or are not a currently merchantable species. Rotten trees are trees that do not contain a sawlog because of rot (i.e., 50 percent or more of the live cull volume). Salvable dead wood includes downed or standing trees that are considered currently or potentially merchantable. Excess saplings are live trees having a dbh of between 1.0 and 4.9 inches. Small pole trees are trees with a dbh greater than 5 inches, but smaller than saw timber trees. (back to report)

2. Retrieval efficiency accounts for the quantity of the inventory that can actually be recovered due to technology or equipment (assumed to be 40 percent). It is assumed that 50 percent of the resource is accessible without having to construct roads, except for logging residues for which 100 percent of the inventory is assumed accessible. Finally, inventory that lies on slopes greater than 20 percent or where conventional equipment cannot be used are eliminated for cost and environmental reasons. (back to report)

3. The assumed residue factors are--1 ton of corn stover for every 1 ton of corn grain produced; 1.7 tons of wheat straw for every 1 ton of winter wheat grain; and 1.3 ton of wheat straw for every 1 ton of spring and duram wheat grain (Heid, 1984). We assume a grain weight of 56 and 60 lb/bu for corn and wheat grain respectively. Grain moisture factors are assumed to be 1 for corn and .87 for wheat. (back to report)