SOL OPTIMA
A Division of United Spectra

ALGAE OPTICS

Michael Brininstool

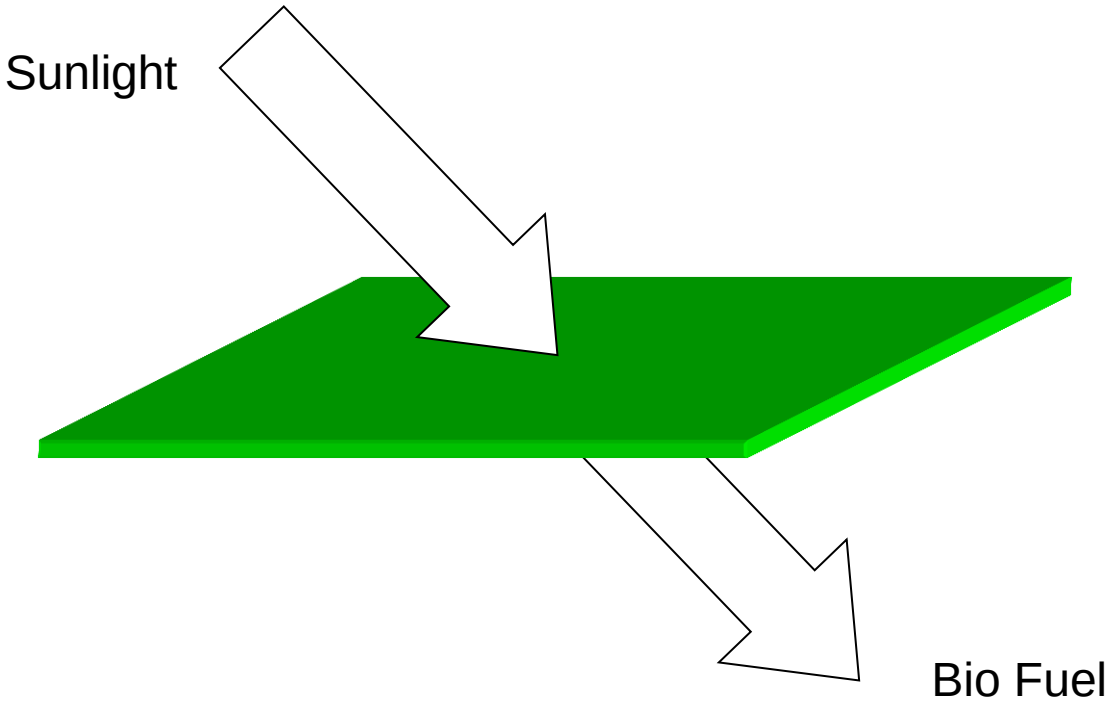
Sol Optima

(858) 200-6060
Brininstool@UnitedSpectra.com

SOL OPTIMA
A Division of United Spectra

Algae Optics Challenge

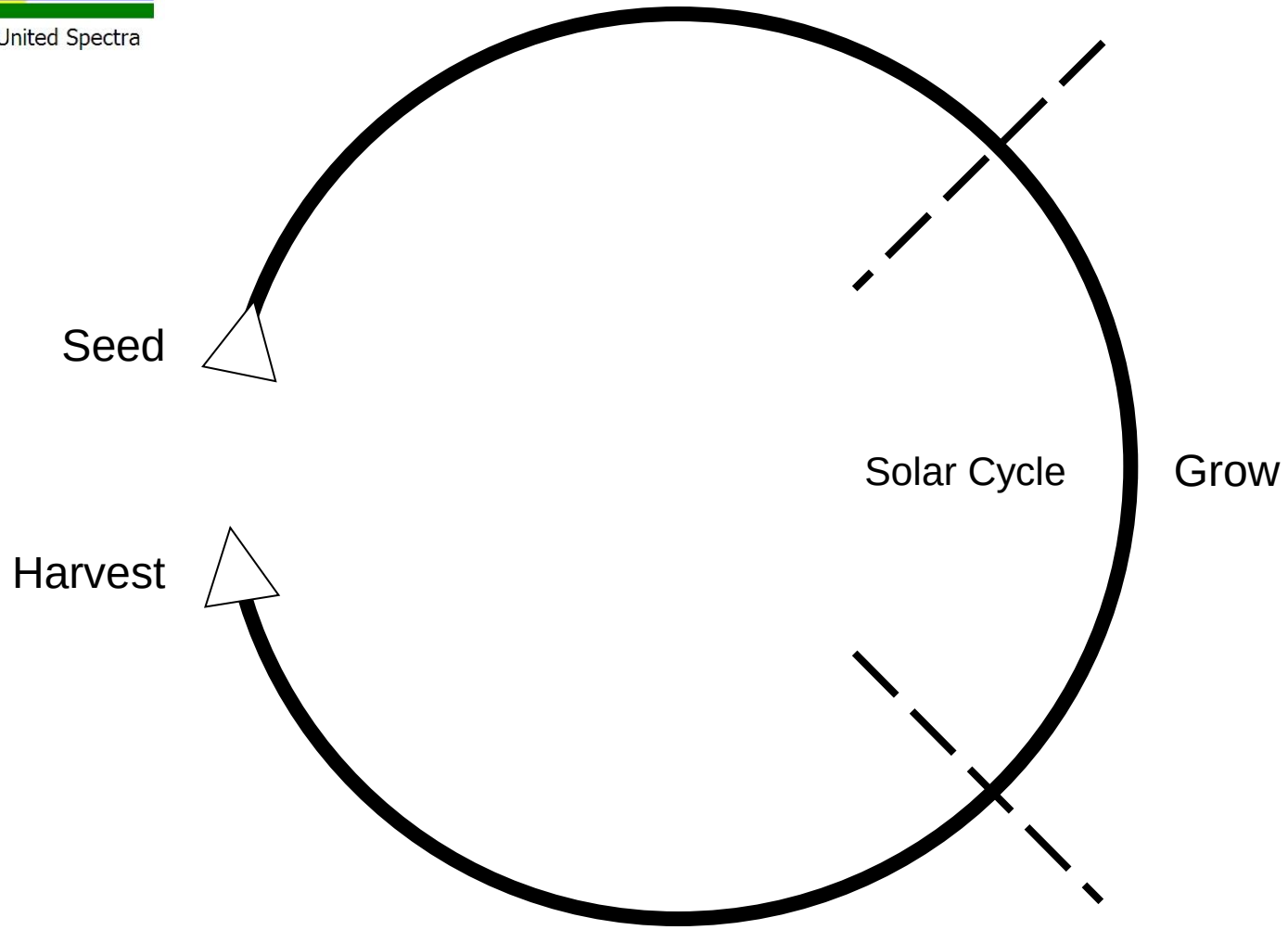
Maximize conversion of renewable energy source (sunlight) into a consumable energy product (biofuel).



SOL OPTIMA

A Division of United Spectra

Algae to Oil Production Cycle



Reactor Geometries

Open Pond: Large Area, Shallow

No matter what the shape of the reactor, designs are driven by manipulating the volume parameters:

Temporal
Spatial
Spectral
Chemical
Mechanical
Thermal
Electrical

Power
Time
Area

Open Container: Smaller Area, Deep

SOL OPTIMA
A Division of United Spectra

Algae Optics Goal:

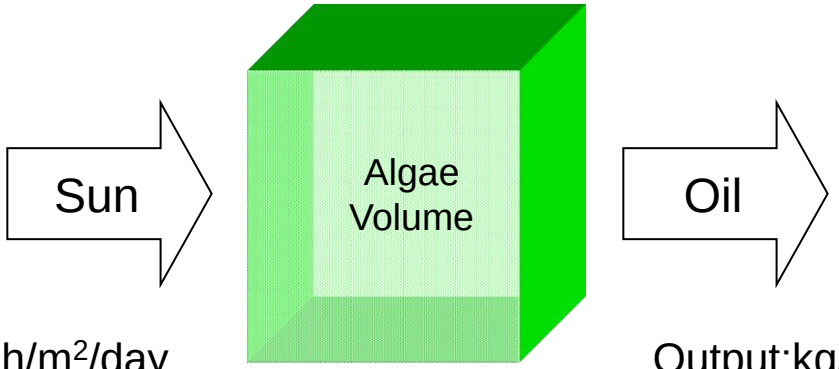
Maximize photosynthetic efficiency.

Approach – Manage all properties of solar radiation.

Temporal

Spatial

Spectral



Input: kW-h/m^2/day

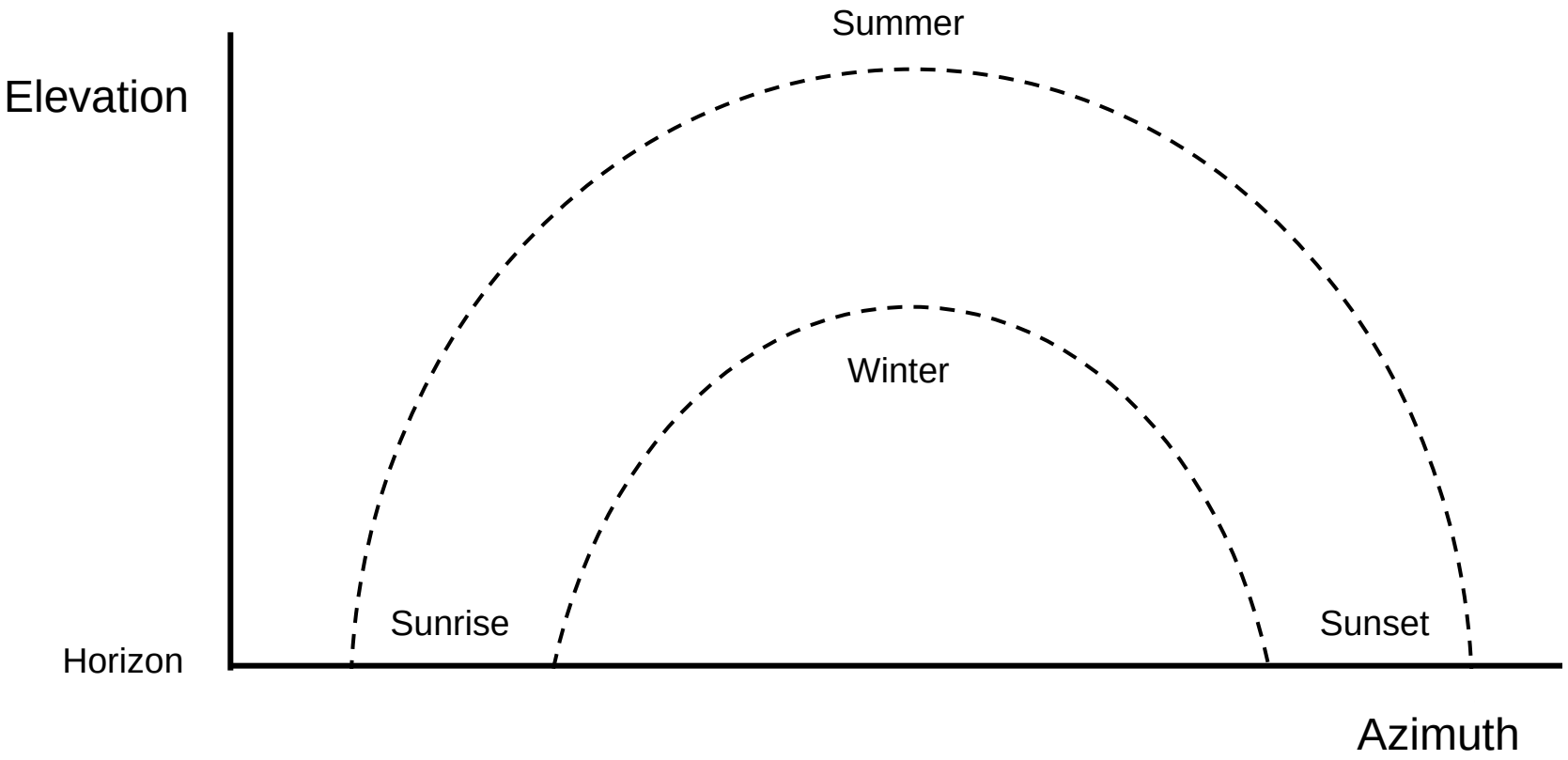
Output:kg/m^2/day

Performance Metric Output/Input: kg / kW-h

SOL OPTIMA
A Division of United Spectra

Design Considerations – Temporal

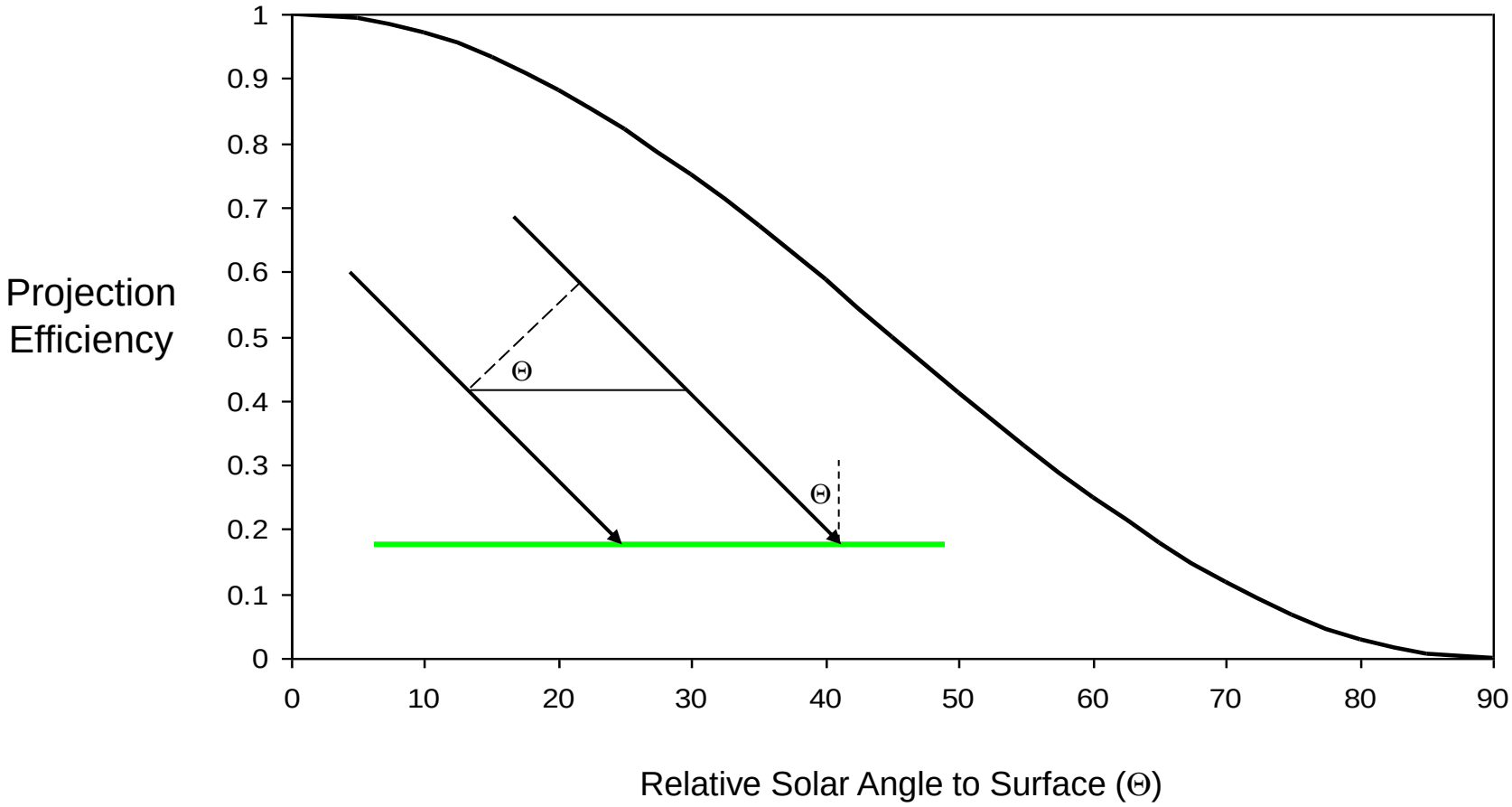
Solar Tracking



SOL OPTIMA
A Division of United Spectra

Design Considerations – Temporal

Solar Tracking



SOL OPTIMA
A Division of United Spectra

Design Considerations – Temporal

Solar Tracking

Tracking maximizes projection overlap. Open ponds do not track.

Tracking techniques:

Mechanical
: Fixed and mobile, gymbals, pan and tilt

Opto-mechanical
: Shutters, baffles

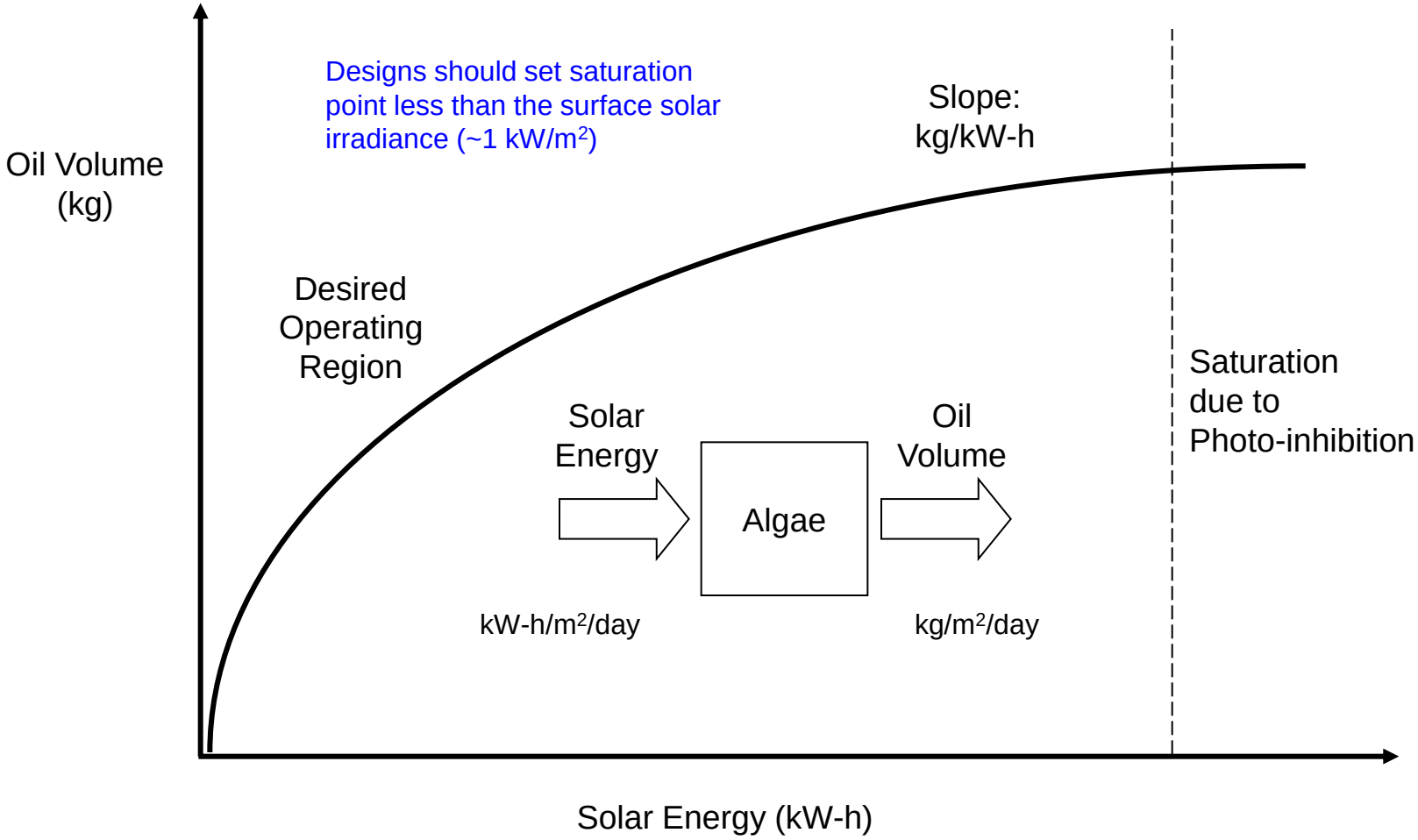
Opto-electrical
: Switches, shutters, Sources: LEDs, Lasers, Other

All Optical
: Waveguides, lenses, filters, splitters, mirrors

SOL OPTIMA
A Division of United Spectra

Design Considerations – Temporal

Photo-inhibition

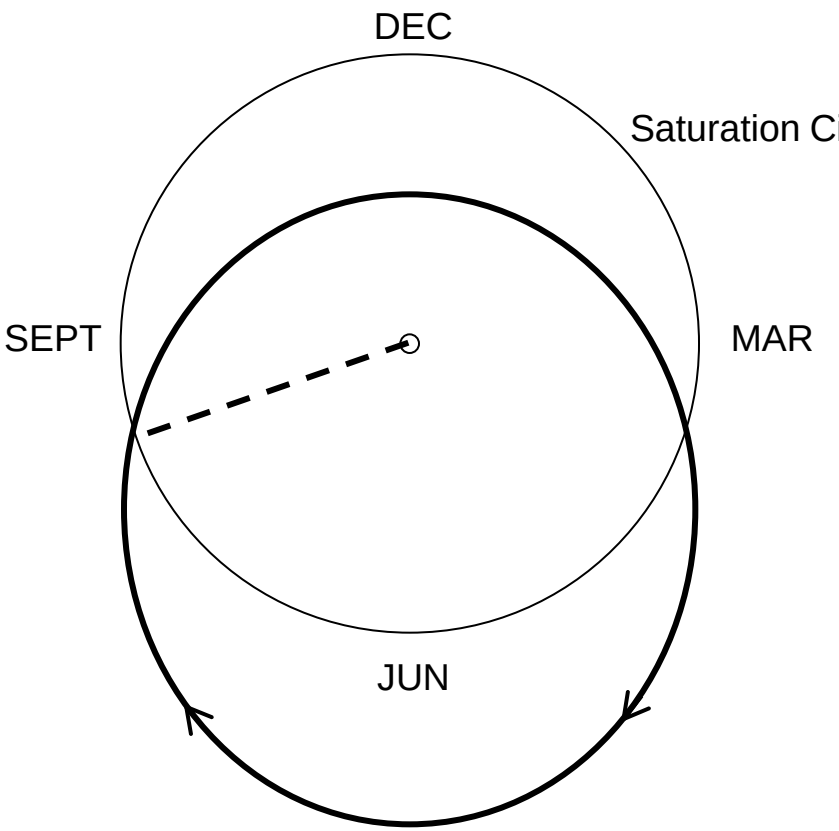


SOL OPTIMA
A Division of United Spectra

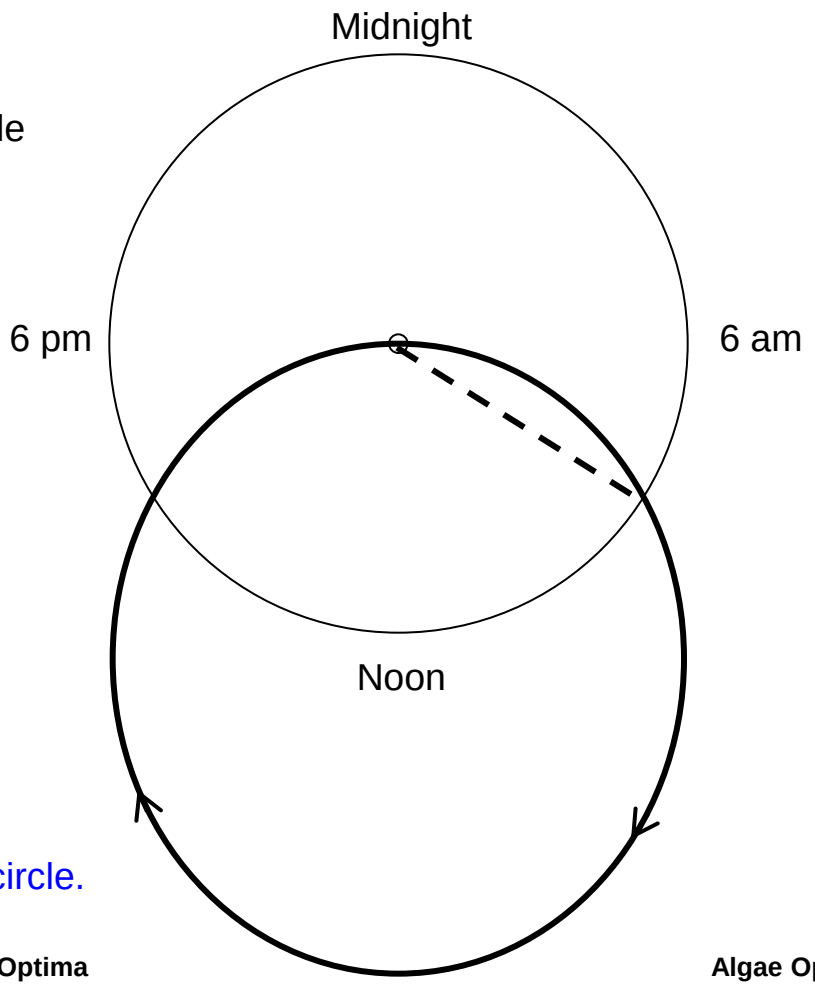
Design Considerations – Temporal

Solar Cycle – Photo-inhibition

Year Cycle



Day Cycle



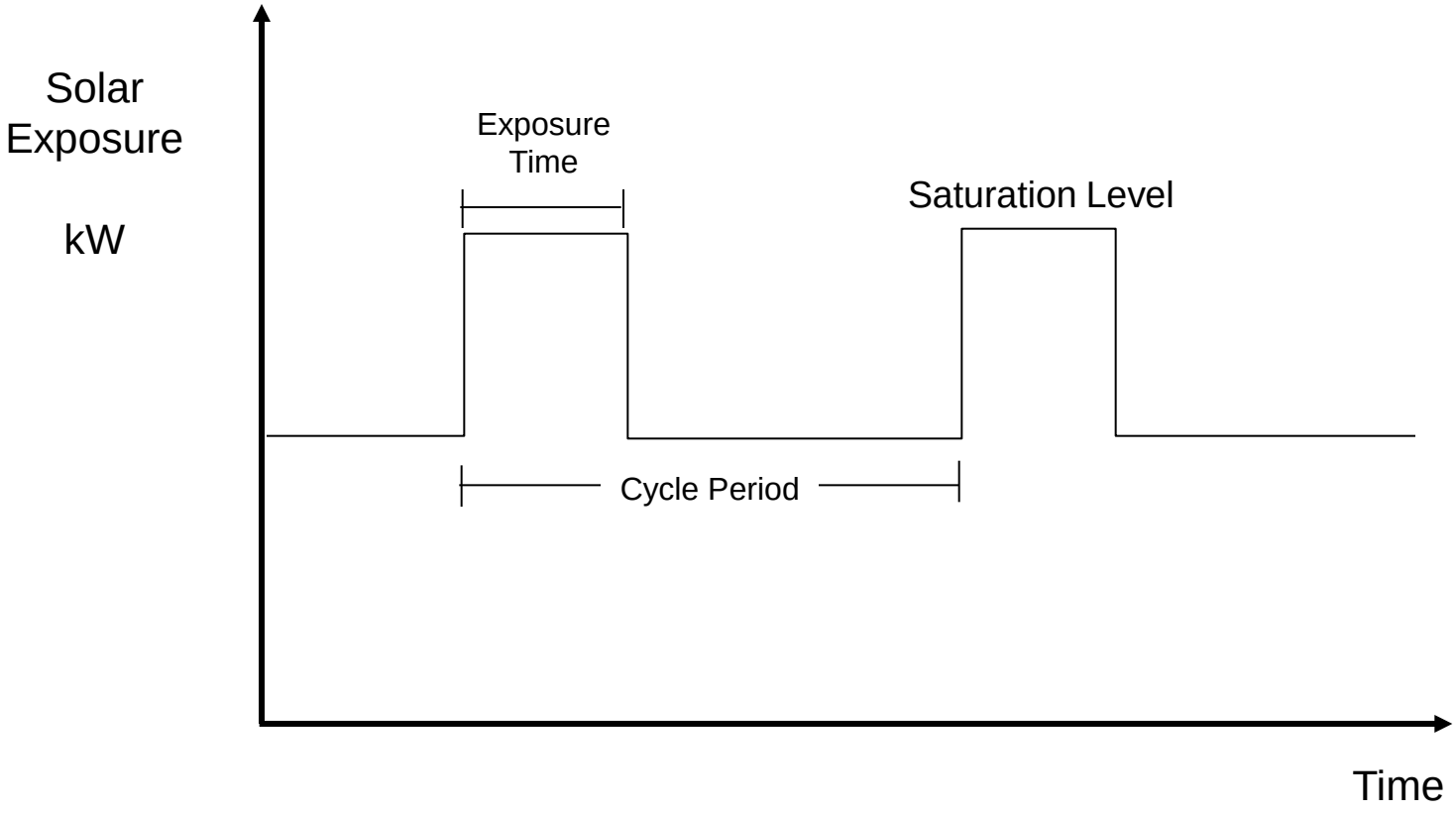
Must stay inside saturation circle.

SOL OPTIMA
A Division of United Spectra

Design Considerations – Temporal

Photo-inhibition

Photo-inhibition calls for cyclic exposure of species.



SOL OPTIMA
A Division of United Spectra

Design Considerations – Temporal

Photo-inhibition

Photo-inhibition calls for cyclic exposure of species.

Designs should modulate photo-inhibition (photo-stirring).

Modulation techniques:

Mechanical
: Stirring, circulation of solution

Opto-mechanical
: Shutters, baffles

Opto-electrical
: Switches, shutters, Sources: LEDs, Lasers, Other

Opto-chemical
: Dyes

All Optical
: Waveguides, lenses, filters, splitters, mirrors

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Concentration of Surface Irradiance (W/m^2)

Technologies for Solar Concentrators

<u>Optical</u>

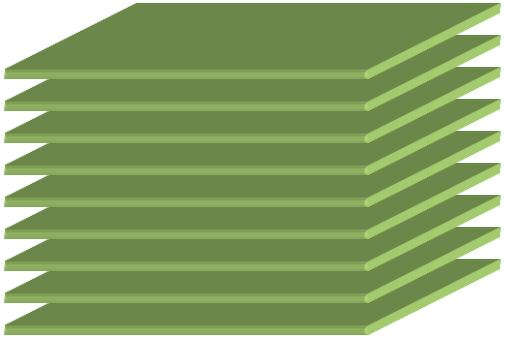
- Lenses
- Beam splitters
- Mirrors
- Gratings
- Filters
- Waveguides –
  - Glass Fiber
  - Acrylic Polycarbonate

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Optimization of Volume

Shallow surface area requires photo-stir to manage saturation effects.



Deep volume with <u>uniform illumination</u> at all depths.

Ideal: All ”layers” receive solar energy just below saturation.

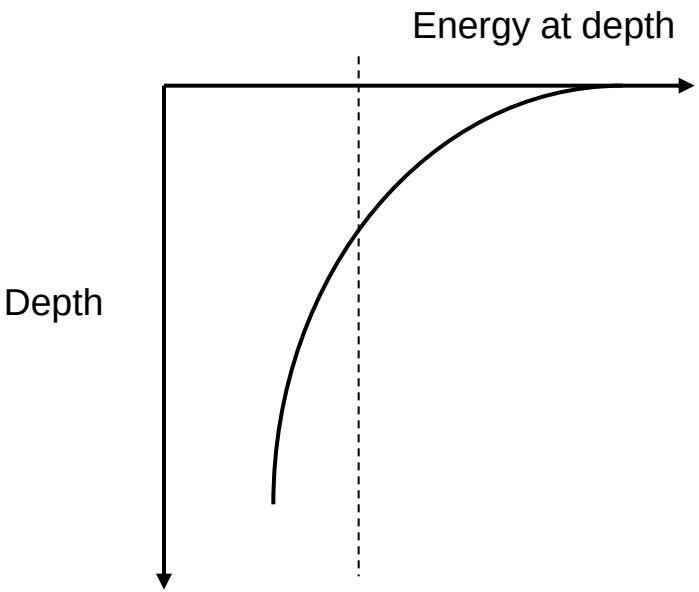
Limit: Sun only provides fixed amount of kW-h/m^2/day

Production Metric is kg/m2/day

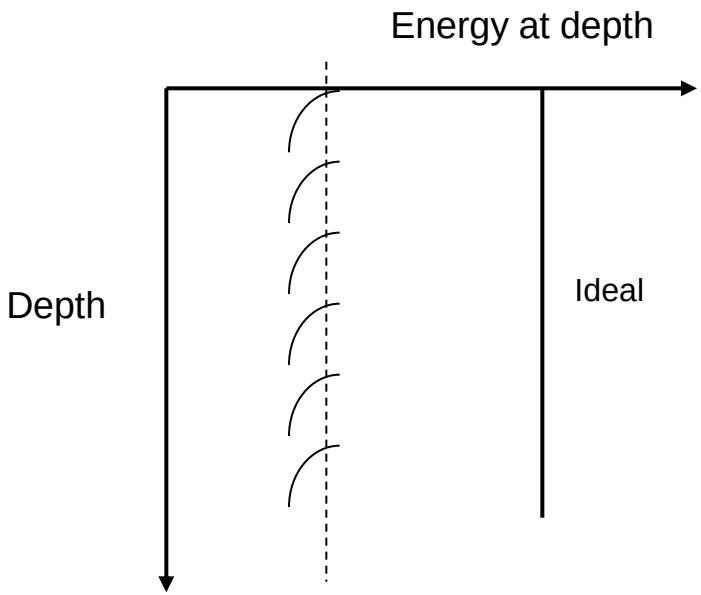
SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Optimization of Volume



Natural Surface Illumination –
Spectral attenuation limits penetration depth



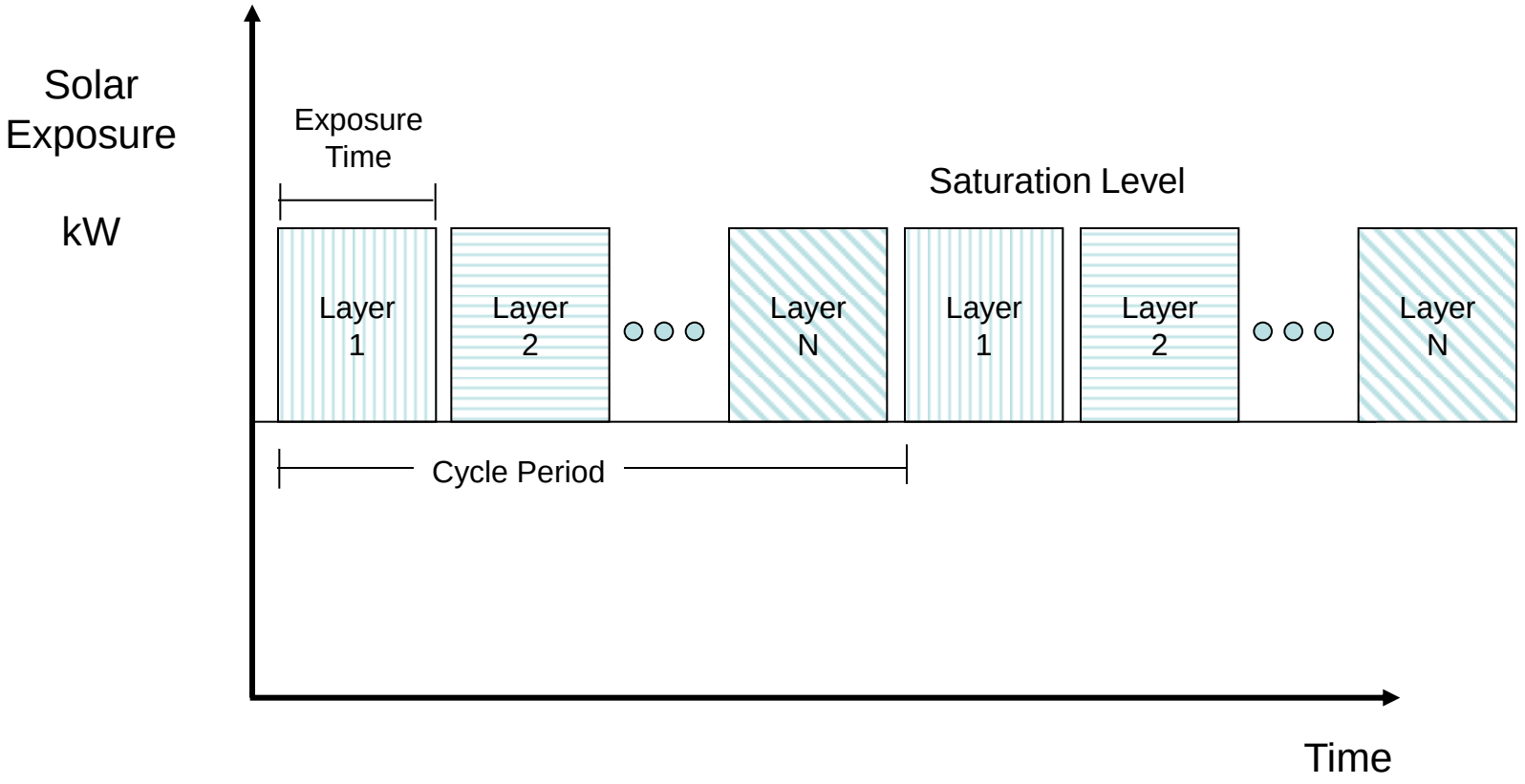
Optical Spatial Distribution -
Ideal: Uniform lllumination at all depths

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Photo-inhibition

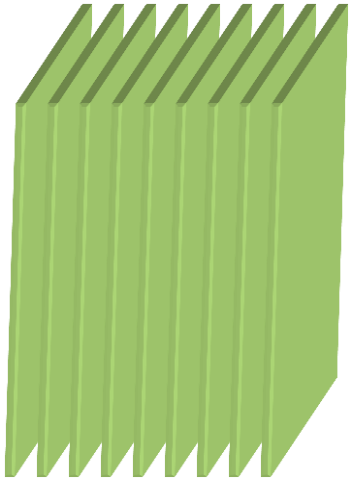
Photo-inhibition calls for cyclic exposure of species.



SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Optimization of Volume



Deep volume with uniform illumination at all depths.

Ideal: All ”layers” receive solar energy just below saturation.

Slice volume to distribute light deeper.

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Optimization of Volume

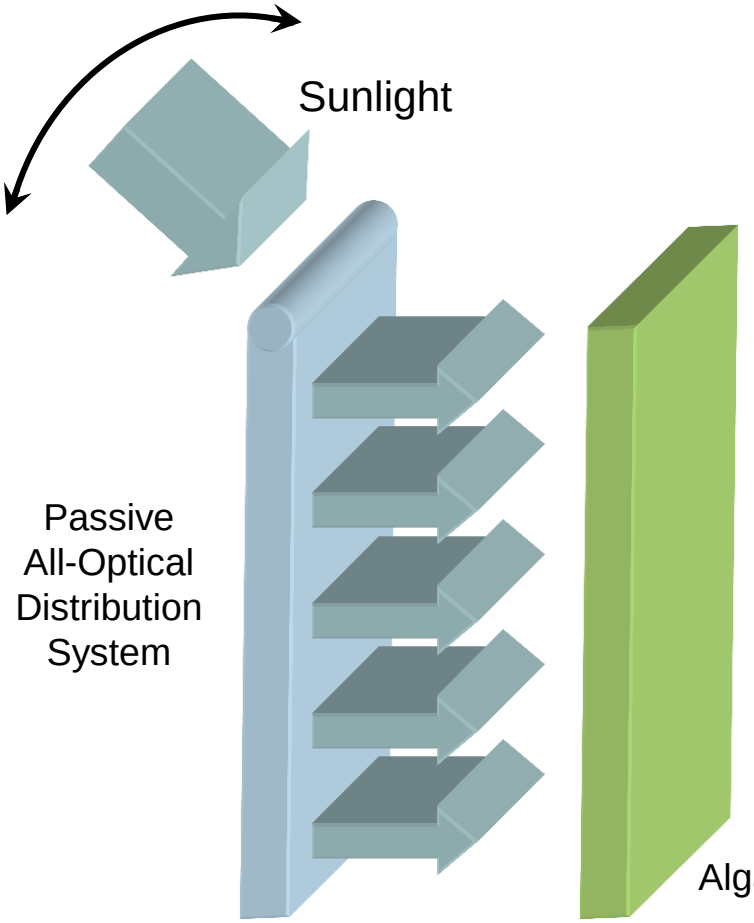
Technologies for Optimization of Volume Illumination

- Mechanical
  - Stir volume to expose solution uniformly
- Electro-optical
  - Use indirect light sources to distribute light
- Optical
  - Waveguides, lenses, filters,
  - Mirrors, beam splitters
- Hybrids

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Optimization of Volume : All-Optical



All-Optical Distribution System

Track and capture light at surface

Carry light deep into volume

Deliver light evenly at all depths.

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Optimization of Volume : All-Optical

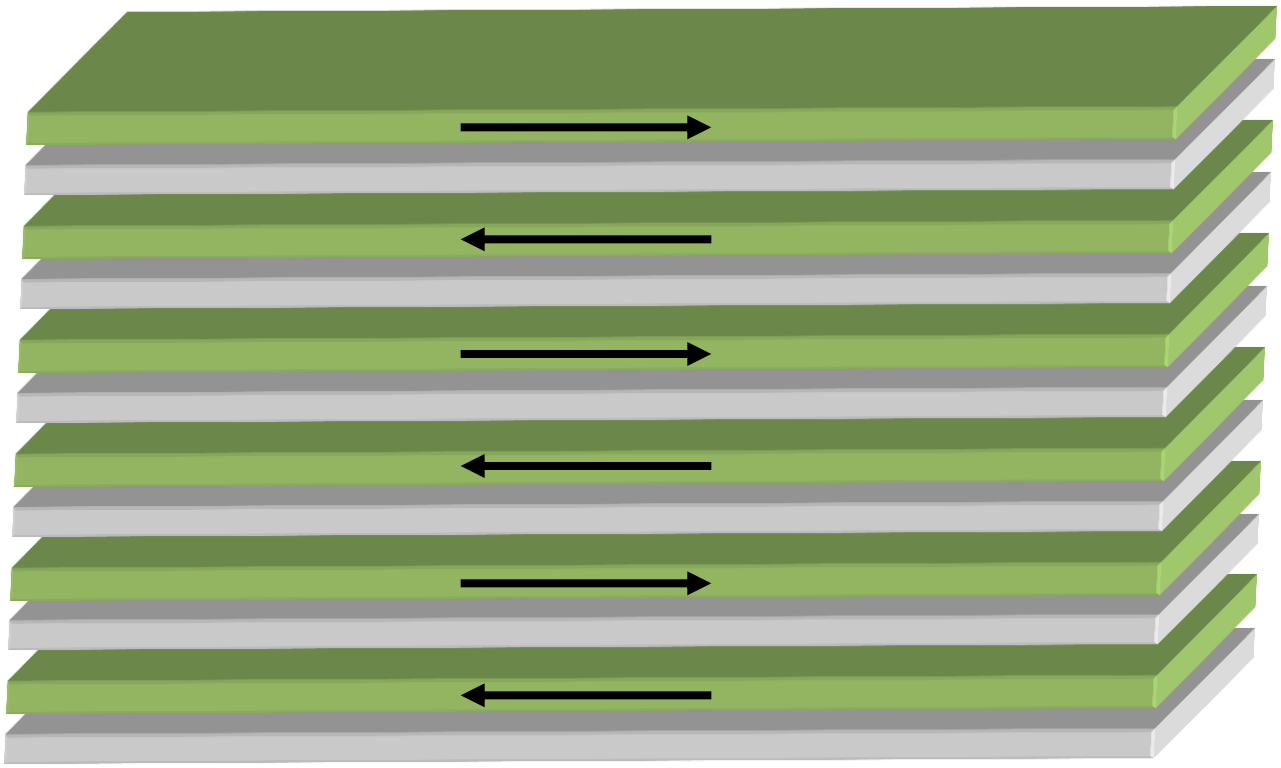
Optical Design Parameters

Track optics: f- number, lens shape, aperture size
Waveguide: material, thickness, split ratio, grating modulation, dye density, numerical aperture, guide attenuation
Splitters: ratios, grating spectral response

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spatial

Optimization of Volume : Hybrid Example



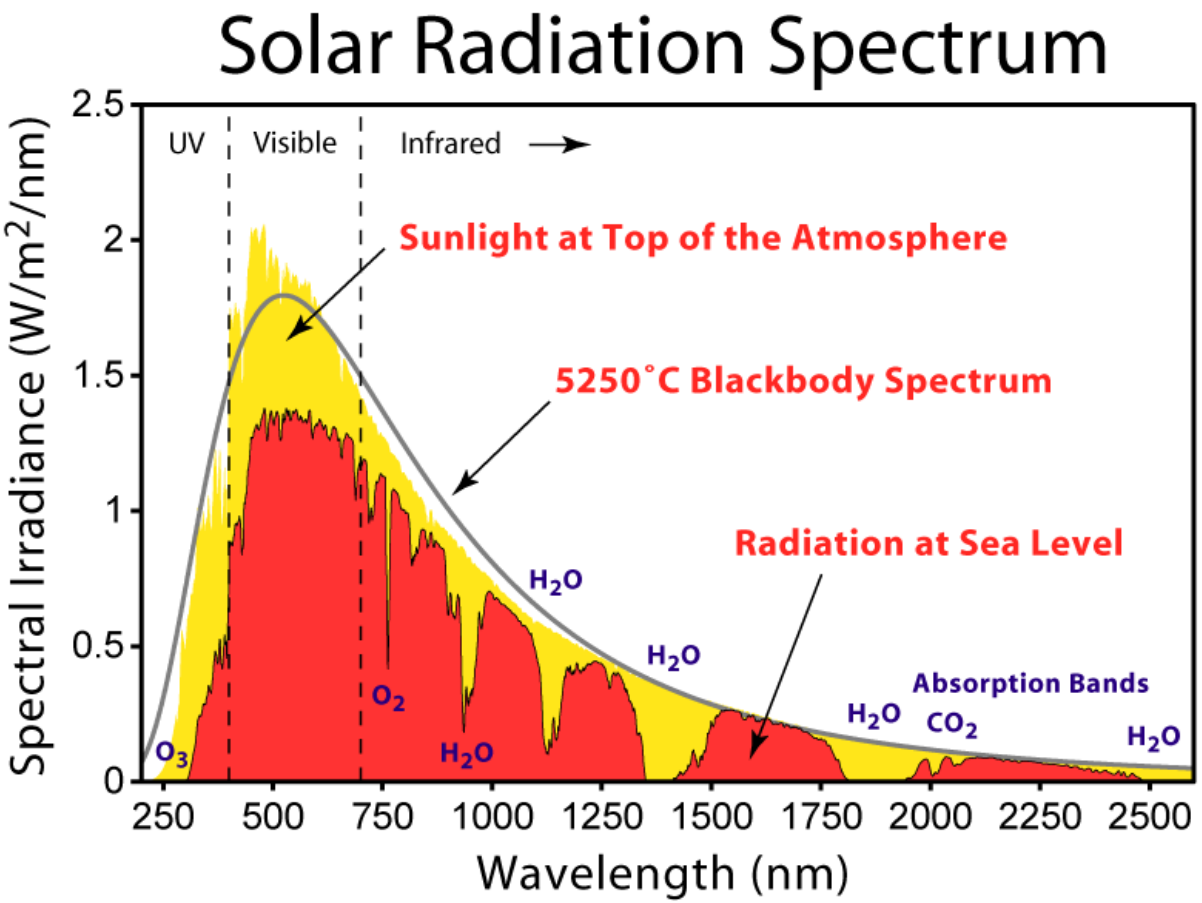
Penetration Layers:

Hybrid of
All-optical delivery from solar and layered electro-optical illumination. Channels and layers are circulated at rate dependent on species' saturation level requirements.

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spectral

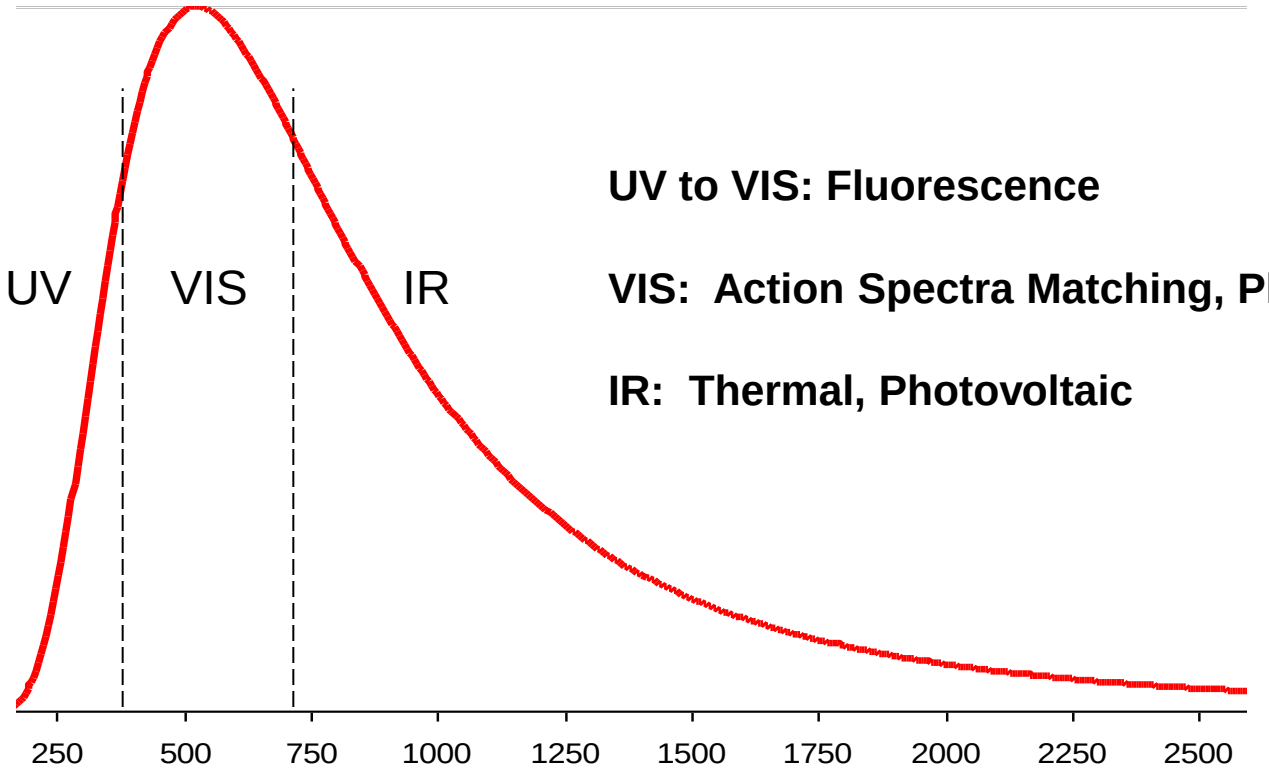
Optimal Utilization of Solar Spectrum



SOL OPTIMA
A Division of United Spectra

Design Considerations – Spectral

Spectral Management



UV to VIS: Fluorescence

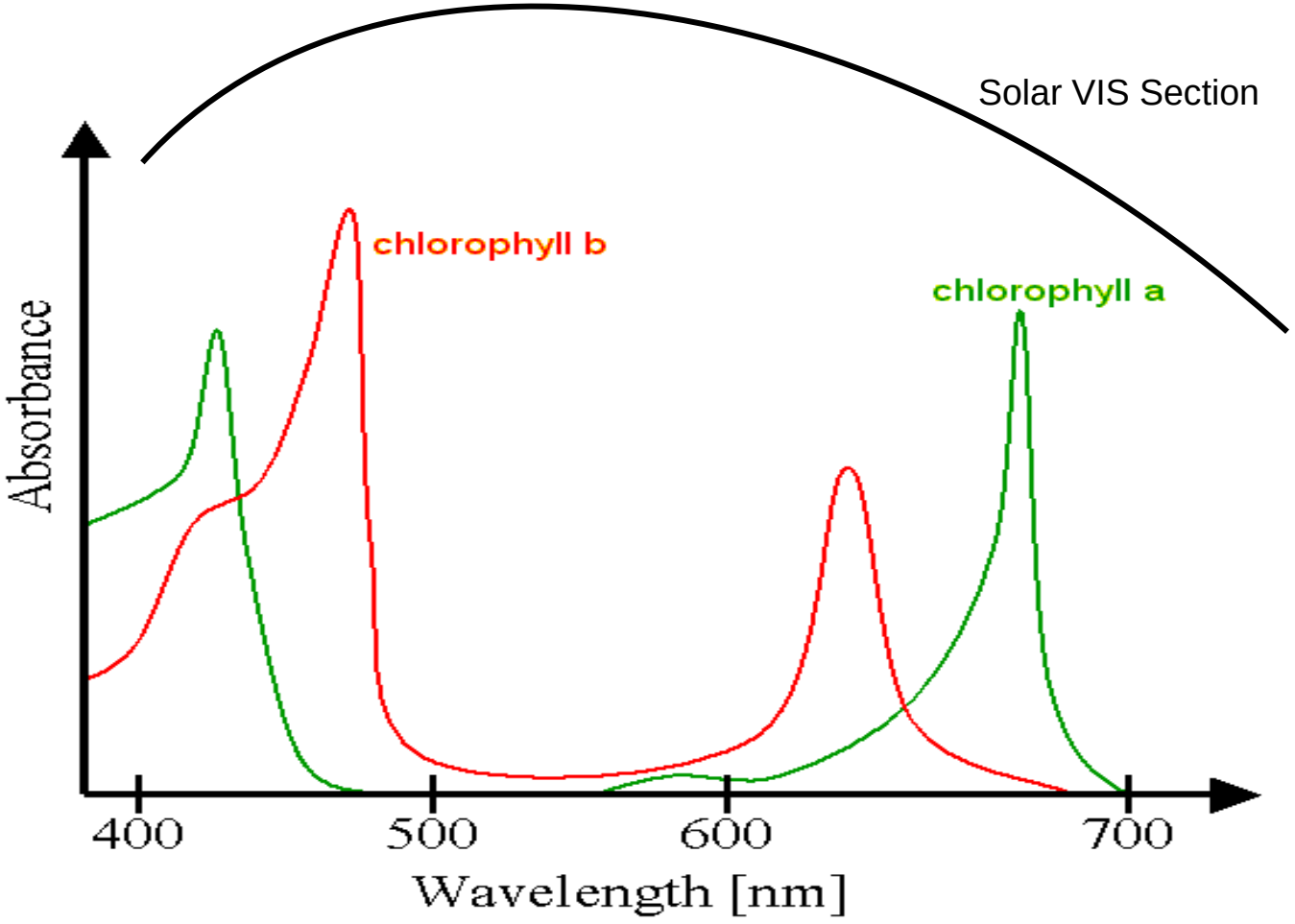
VIS: Action Spectra Matching, Photovoltaic

IR: Thermal, Photovoltaic

SOL OPTIMA
A Division of United Spectra

Design Considerations – Spectral

Action Spectra - Chlorophyll



SOL OPTIMA
A Division of United Spectra

United Spectra Assets

Optical Expertise

Modeling
Design
Testing
Production
Installation
Publications
Training

Intellectual Property

SOL OPTIMA
A Division of United Spectra

United Spectra Expertise

Optical Disciplines

Fiber Optics
Free Space Optics
Solar Energy

Customers

Government - Military, Municipalities
Commercial

Applications

Communications
Sensors
Instrumentation
Energy

Technologies

Electro-mechanical
Electro-optical
All Optical

SOL OPTIMA
A Division of United Spectra

United Spectra IP Assets

Communications and Instrumentation

Devices

"Broadband Optical Aperture" Pending
"Coiled Optical Bragg Refracting Aperture (COBRA)" U.S. Patent No. H0002180
"Concatenated Optical Radiating Aperture – Linear Array" Pending (CORAL)
"Vertically Indexed Power Emitting Radiator" Pending (VIPER)
"Coiled optical Bragg radiator with power radiation enhancement" Pending (RATTLER)
"Broadband Fiber Bragg Grating Coupler" Pending
"Tunable Planar Waveguide Lens" Pending
"FBG Coupler with Graded-index Fiber Lens" Pending

Modules

"Suspended Optical Fiber Transceiver" Pending (SOFT Ball)
"Broadband Modulating Retro-Reflector with In-line Optical Gain" Pending
"Tunable Spatial Filter for Radial Sunlight Rejection" Pending
"Full (4p steradian) coverage, spherical radiating optical aperture" Pending (MEDUSSA)

Instrumentation/ Measurements

"Integrated Optical Time Domain Reflectometer/ Insertion Loss Measurement System", U.S. Patent No. 4,685,799
"Fiber Optical Time Delay Resonant Oscillating Strain Gauge", U.S. Patent No. 4,725,728

SOL OPTIMA
A Division of United Spectra

United Spectra IP Assets

Sensors

Opto-Mechanical

“Fiber-Optic Remote Angular Position Sensor Including A Polarization Track”, U.S. Patent No. 5,073,711
"Fiber-Optic Angular-Orientation Sensor Using Digital Serial Encoding”, U.S. Patent No. 5,042,157
"Remote Fiber-Optic Angular-Orientation Sensor Using Phase Detection of Two Orthogonal Oscillating Polarization Vectors”, U.S. Patent No. 4,958,072

Electro-optical

“Tunable Spatial Filter for Radial Sunlight Rejection” Pending

All-optical

“Multiplexing Technique for Interferometric Fiber Optic Sensor”, U.S. Navy Case No. 76631, Patent Pending
“Fiber Optic Self-Multiplexing Amplified Ring Transducer and Force Transfer Sensor with Pressure Compensation”, U.S. Patent No. 5,589,937

SOL OPTIMA
A Division of United Spectra

United Spectra and Algae

United Spectra offers optical expertise to assist in implementing the goals of the bio-fuels community:

Maximize photosynthetic efficiency.