



## CONN CENTER FOR RENEWABLE ENERGY RESEARCH

# Thin Film Roll-to-Roll Deposition Equipment at the Conn Center Solar Manufacturing R&D Laboratory

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## Introduction

The thin film roll-to-roll deposition equipment at the Conn Center Solar Manufacturing R&D Laboratory is intended to aid researchers and companies in developing scalable techniques for the production of renewable energy devices. A variety of thin films up to 15 cm wide can be continuously deposited on flexible substrates via roll-to-roll modular processes. These printing and finishing modules can be configured within the custom designed enclosure to fine tune production schemes.

The Conn Center Solar Manufacturing R&D Laboratory is led by a full time Senior Research Engineer with extensive industry and R&D experience.

This equipment can be useful in numerous ways including:

- Scaling new material depositions
- Advancing lab innovations to pilot scale
- Testing new manufacturing processes at production speed
- Optimizing in-line feedback and quality control
- Manufacturing scaled devices for durability
- Prototyping supporting new venture fund raising

# Controls

The Roll-to-Roll equipment is controlled through two Mitsubishi FX3 Programmable Logic Controllers (PLC) using LabView as the human-machine interface (HMI) running on a Windows PC. The PLCs and the PC communicate through an ethernet connection. This enables a simple, familiar, programmable HMI for students and professionals to configure operation. All machine controls are wired through three emergency stops.

FIGURE 2.1 External Control Cabinets



OVERVIEW

1. Unwind/Rewind Programmable Logic Controller (PLC)

2. Process PLC
- The two supervisory PLCs communicate over an ethernet connection. The first PLC is fully programmed to control the Mitsubishi servo motors driving the unwind/rewind modules. The second PLC controls the remaining processes and is designed to be programmed by the user for specific functions including timing, fluid delivery and other process and supervisory tasks. The programming can be done through the supervisory PC using Mitsubishi GX Works software. Generic code for this PLC is available for each process.
- All outputs from the PLC are tied to the emergency stop.

FIGURE 2.2 Table of control modules in Process PLC

COMPONENT	DESCRIPTION
FX3U-48MT/DSS	24 VDC PLC with 48 digital I/O
FX3U-4AD-ADP	4 Analog Input Module
FX3U-4DA-ADP	4 Analog Output Module
FX3U-20SSC-H	2 Axis Positioning Module
FX3U-Enet	Ethernet Communication
MR-J3W-22B	2 Axis Servo Motor Control

Mitsubishi Process PLC

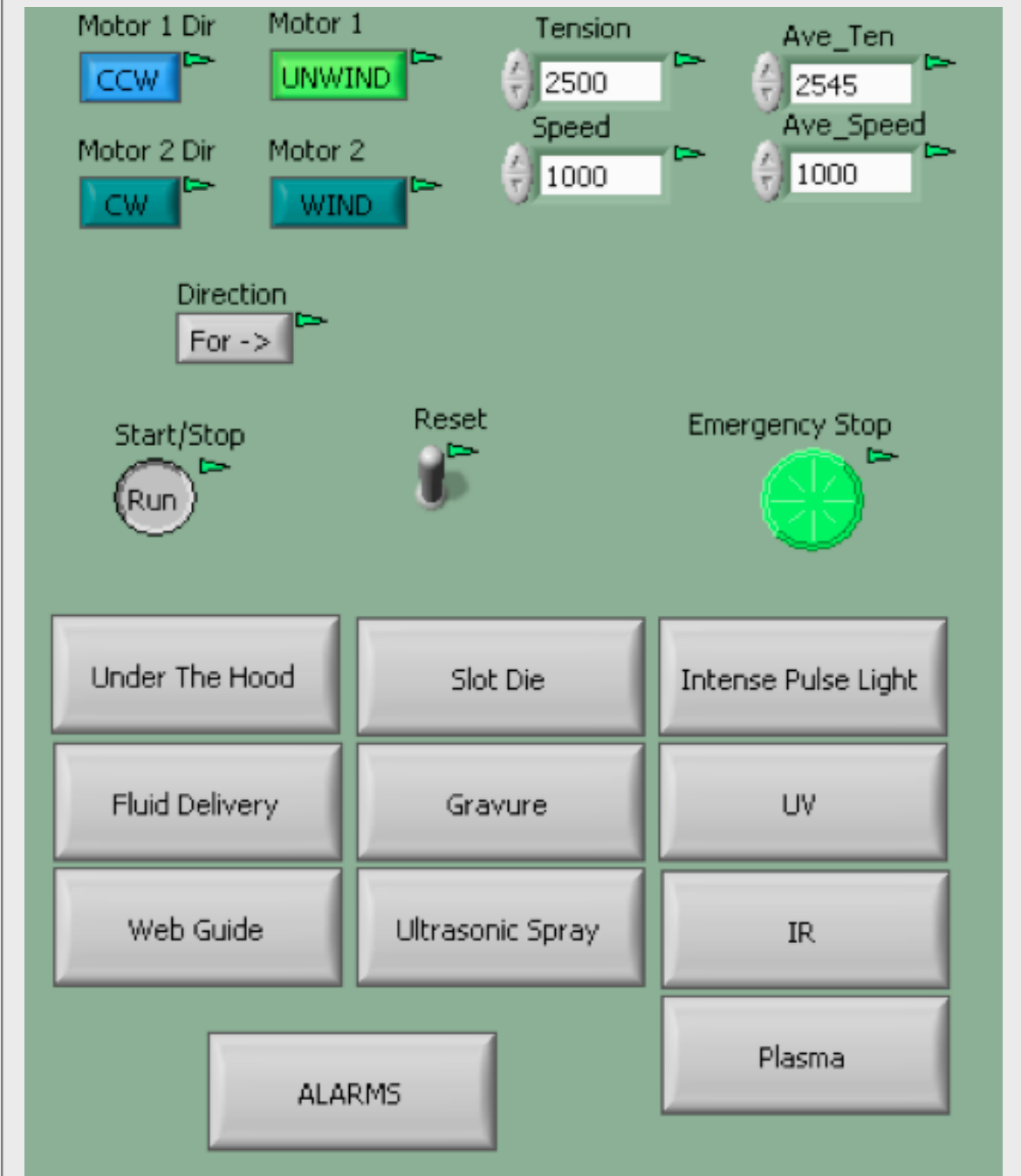
PLC Cabinet

- Input power 240 VAC
- Output 120VAC and 24VDC
- 12-5 pole panel connectors for external modules
- 5 pole 5 meter cord set per connector
- Fused outputs
- Emergency control relay

### OVERVIEW

The two PLCs communicate to a Windows PC via two ethernet connections. The PC is equipped with National Instruments Labview software and includes an open process control (OPC) server for real time data sharing between the HMI and PLCs. Labview is a widely used tool for data acquisition and control and allows a simple programming environment for researchers. The Mitsubishi PLCs offer numerous communication protocols that could be adapted to other HMI systems provided by an end user.

FIGURE 2.3 Main HMI Screen

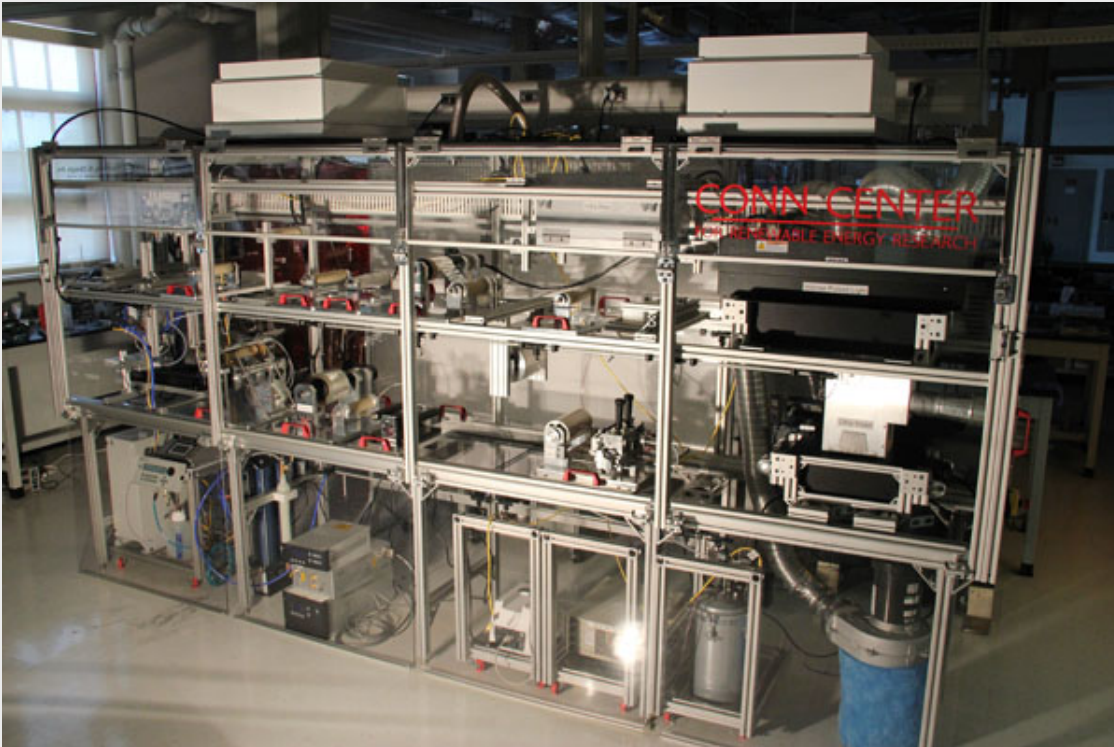


- Main page control
- Buttons access remaining process control pages
- Completely user configurable
- Allows for simple addition of new control pages



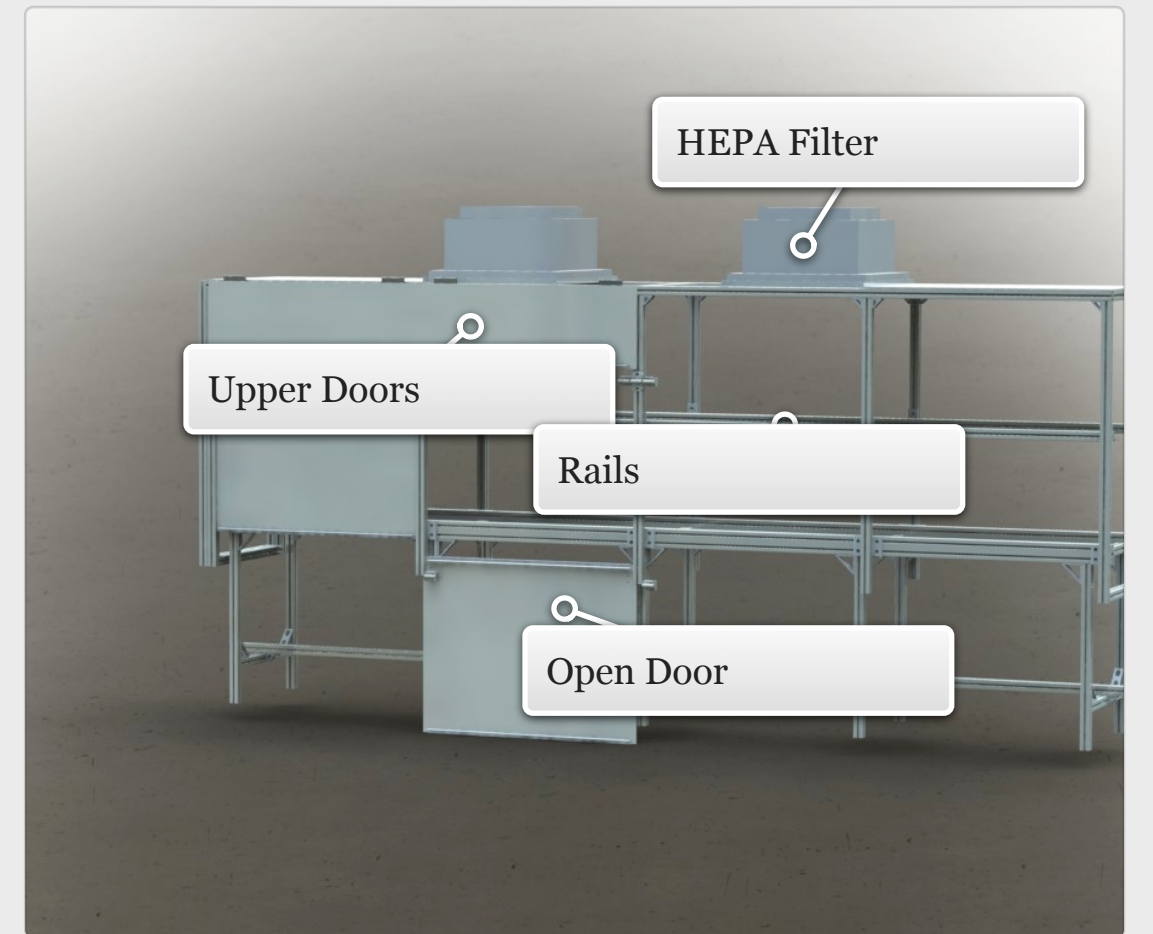
# Enclosure

FIGURE 3.1 Enclosure



The equipment enclosure is a sealed HEPA filtered environment with three mounting level rails for flexible module placement. When opened, the side doors allow complete access to the process modules inside. When closed, operators are safely separated from the equipment.

## INTERACTIVE 3.1 Features of Enclosure

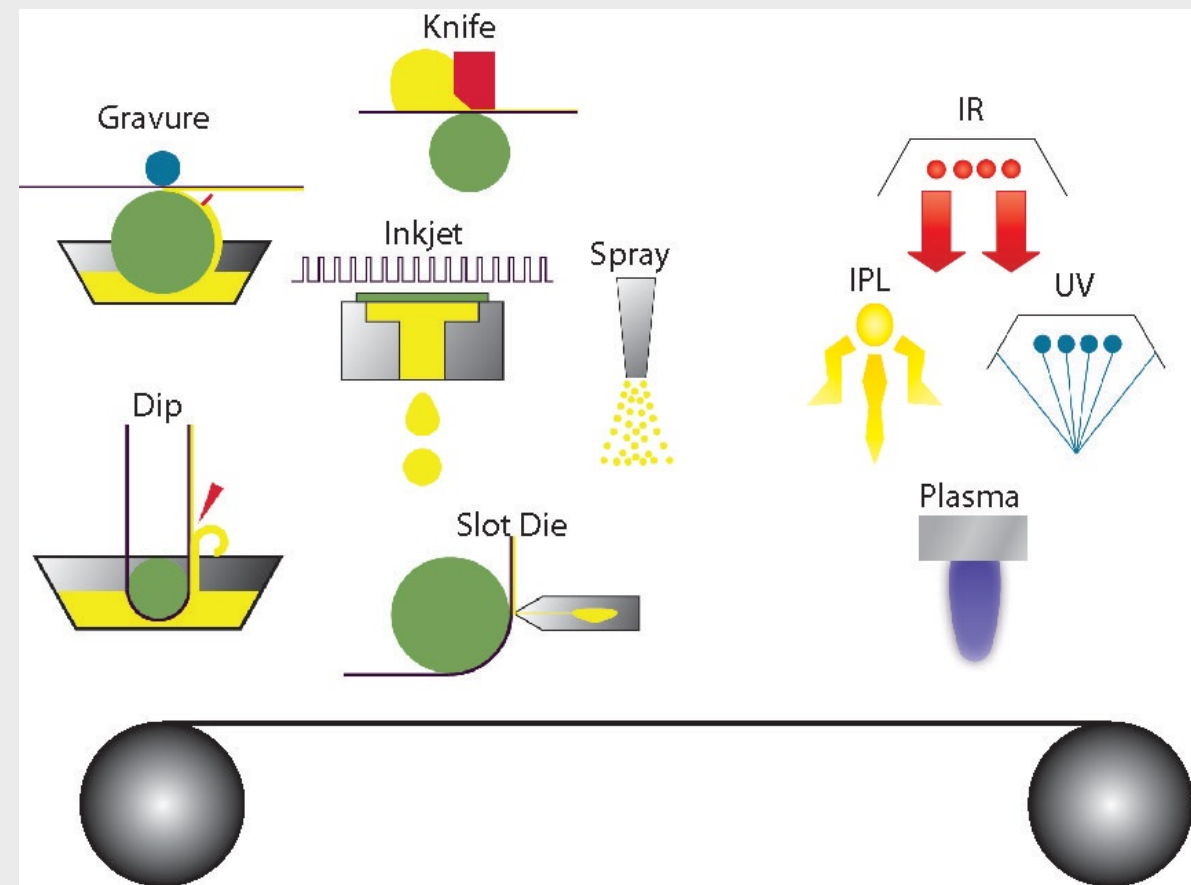


- **Built by Craig Machinery and Design**
- 3 safety switches
- Sturdy 8020 Aluminum Frame Construction
- 3 levels for module placement
- Over 2.5 cubic meters of HEPA enclosed space for modules
- Main doors slide down providing easy access
- Numatics air drier
- 16 air and 8 vacuum taps inside enclosure
- Ample space under HEPA enclosure for fluid delivery systems
- Data and cables connect modules to external PLCs



# Modules

Modular Roll-to-roll setup



Over ten thin film processing modules are available for discrete operation. These modules can be placed on one of three rails throughout the enclosure for custom work flow configurations. New modules can be added as needed.

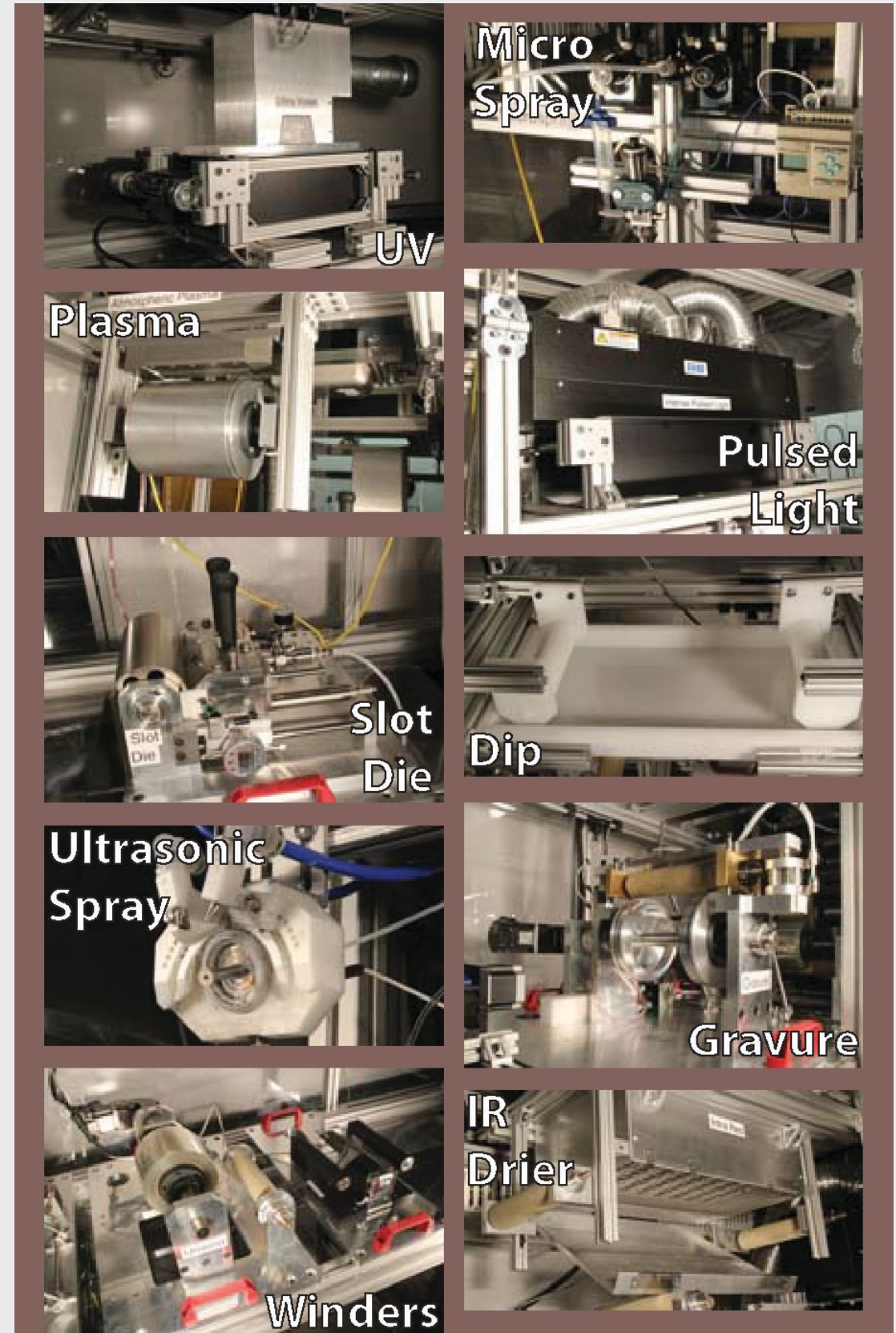
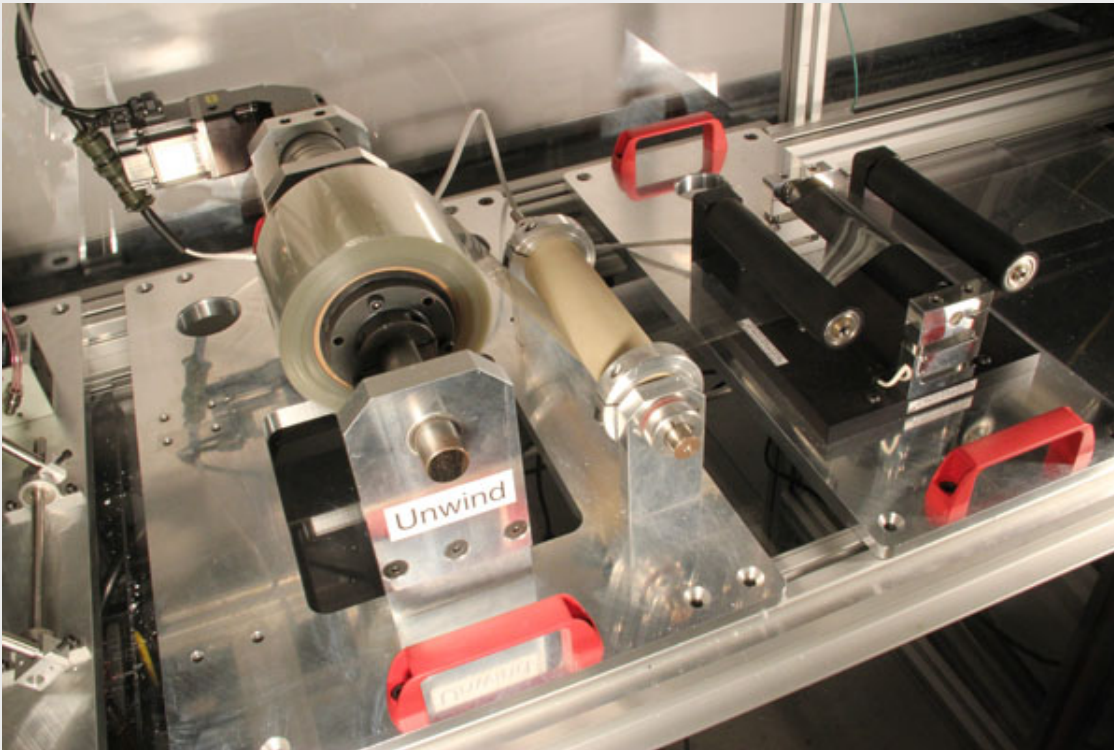




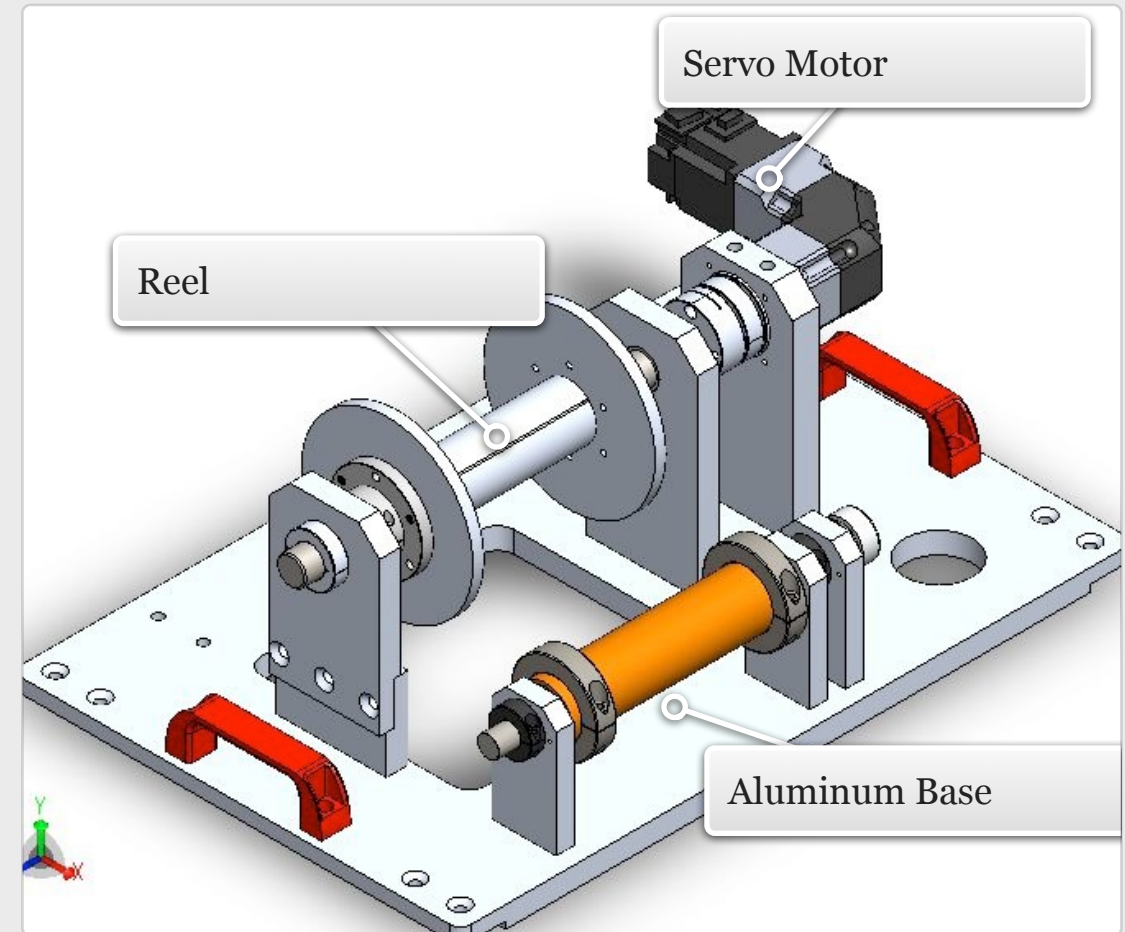
FIGURE 4.1 Unwind and Rewind Modules



### SUMMARY

The primary components for the roll-to-roll equipment are the unwind & rewind modules. Each is powered by a 1/4 hP Mitsubishi motor with tension and speed feedback through a Mitsubishi servo motor controller. The equipment can handle a large range of modulus materials (plastics and metals) at speeds from 1 mm/min to 25 m/min at a maximum tension of 10 kg. This equipment is bi-directional with accurate start/stop capabilities.

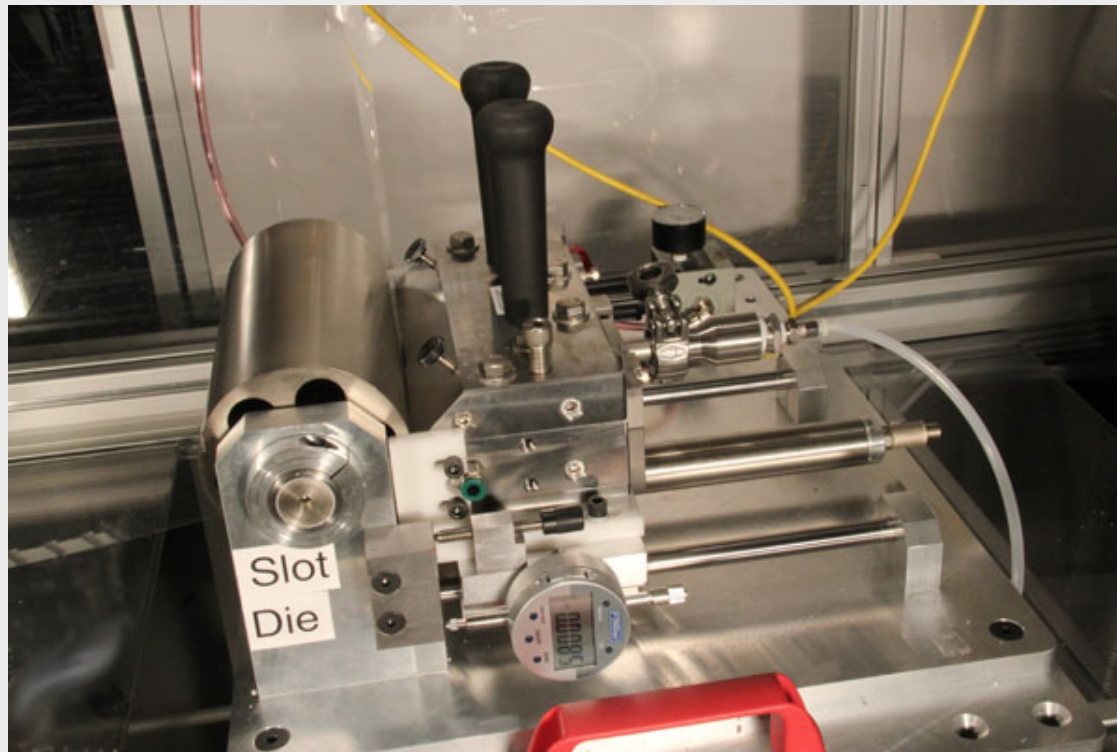
INTERACTIVE 4.1 Unwind/Rewind Assembly



- Two high quality modules (unwind/rewind)
- Each configured with 1/4 hP Mitsubishi Servo Motor
- Speed feedback (1 mm/min - 25 m/min)
- Tension feedback (0 - 10 kg force)
- Smooth bi-directional operation
- Quick start/stop capability
- Mounted onto 1" cast aluminum plate
- Can be mounted to web guide for more accurate positioning
- Configured for 3" and 6" cores

## SLOT DIE

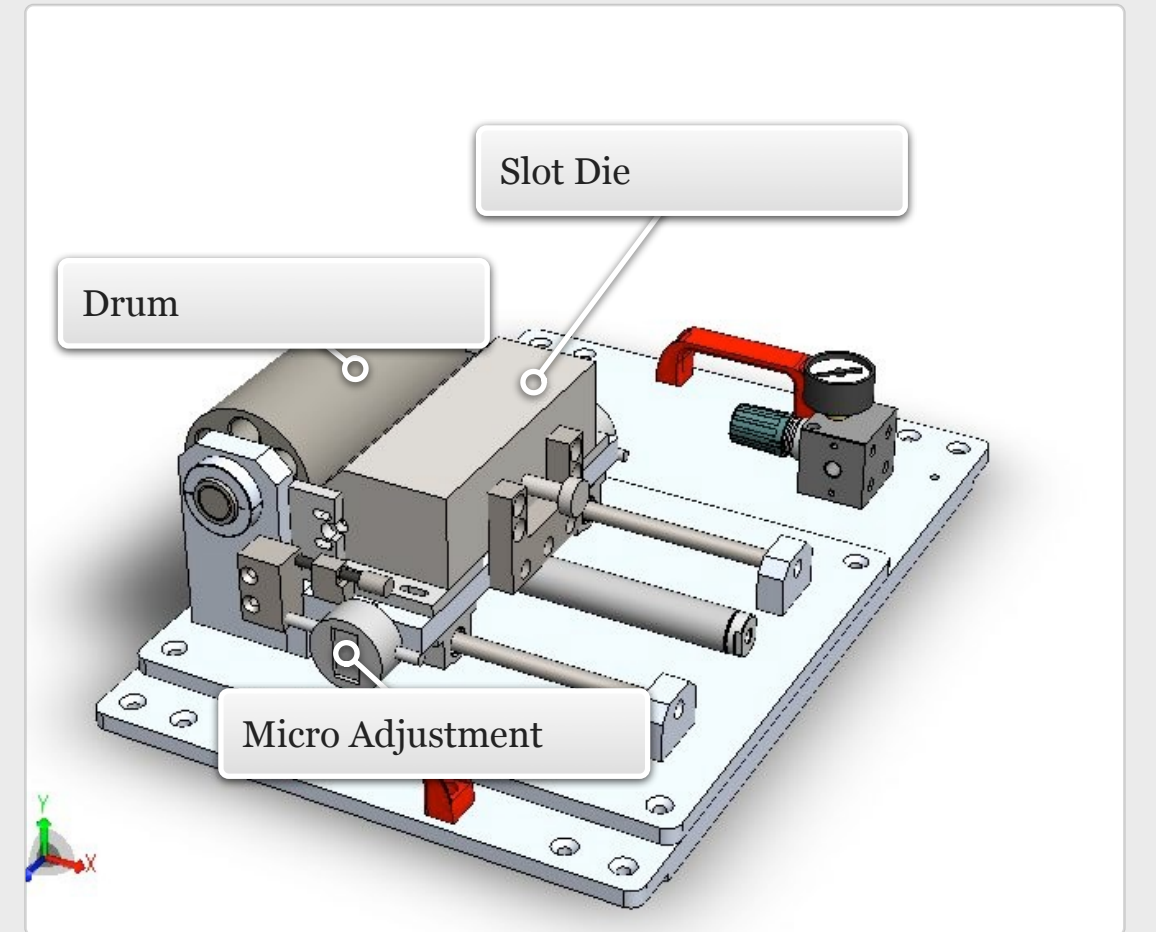
FIGURE 4.2 Slot Die Module



### SUMMARY

The slot die coating is an efficient and versatile tool for thin film coatings utilized in a wide range of industries including solar and battery production. A wide range of material can be deposited at thicknesses ranging from sub micron to 3 mm at viscosities from 1 to 100,000 cP. The material is supplied using a positive displacement pump. This allows application of high solids films and directly reduces processing time and waste.

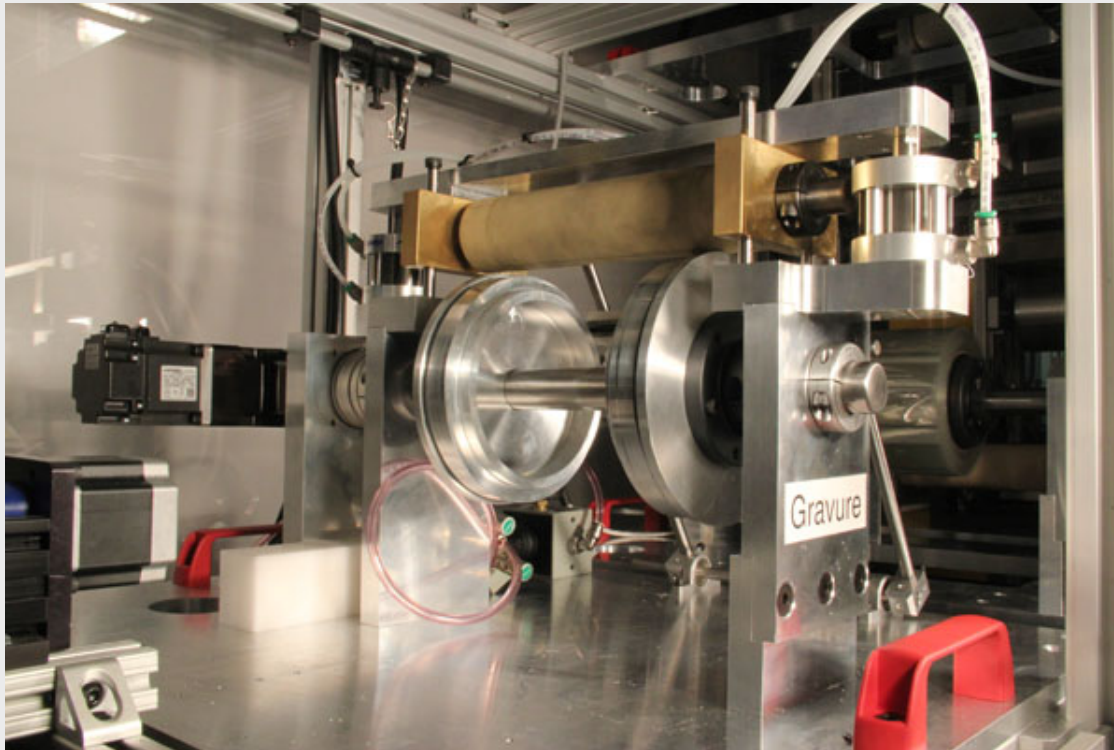
INTERACTIVE 4.2 Slot Die Assembly



- **Premier Dies Versa Die**
- Micro adjustment for accurate positioning
- Can be mounted vertically or horizontally
- 5" diameter nickel plated web drum
- Simple control of slot width and pattern



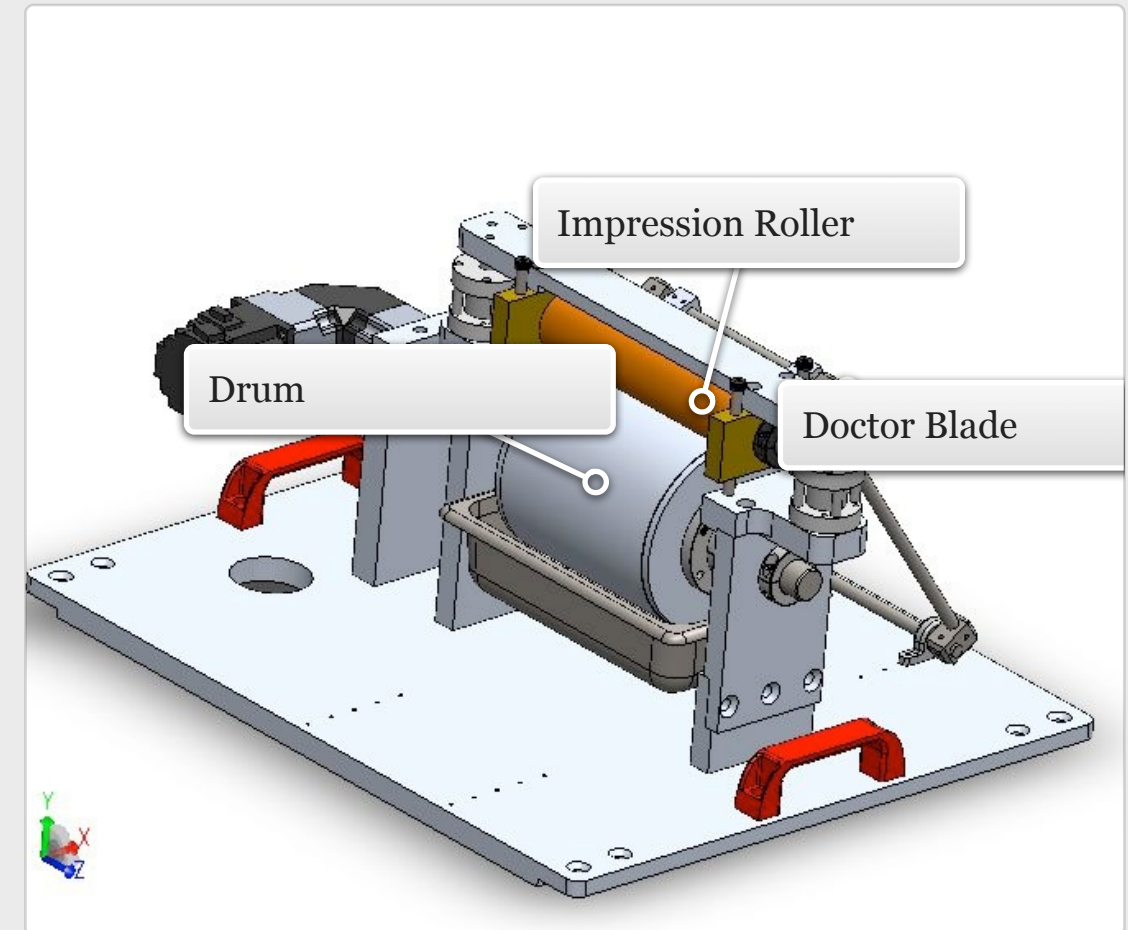
FIGURE 4.3 Gravure Module



### SUMMARY

Gravure coating is a simple and versatile technology utilized throughout graphic and electronics printing. Microcells engraved on the printing cylinder deposit high quality patterned thin films repeatedly along a substrate. Printing cylinders can be made to specification. Both solvent and water based coating formulations can be used and the direct application reduces waste.

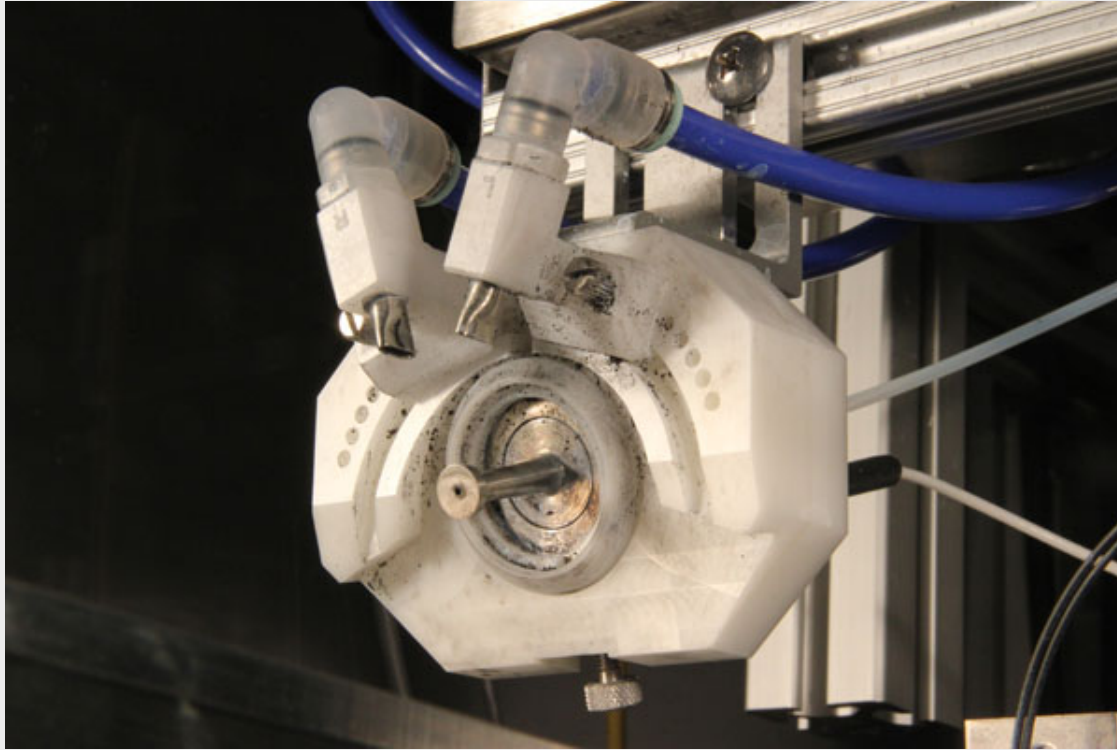
INTERACTIVE 4.3 Gravure Assembly



- **Southern Graphics Systems Screens**
- Controlled impression roller force up to 150 lb.
- Screen driven by servo motor from 1 mm/min to 25 m/min
- Universal doctor blade holder
- Controlled doctor blade angle
- Simple fluid recirculating reservoir

## ULTRASONIC SPRAY

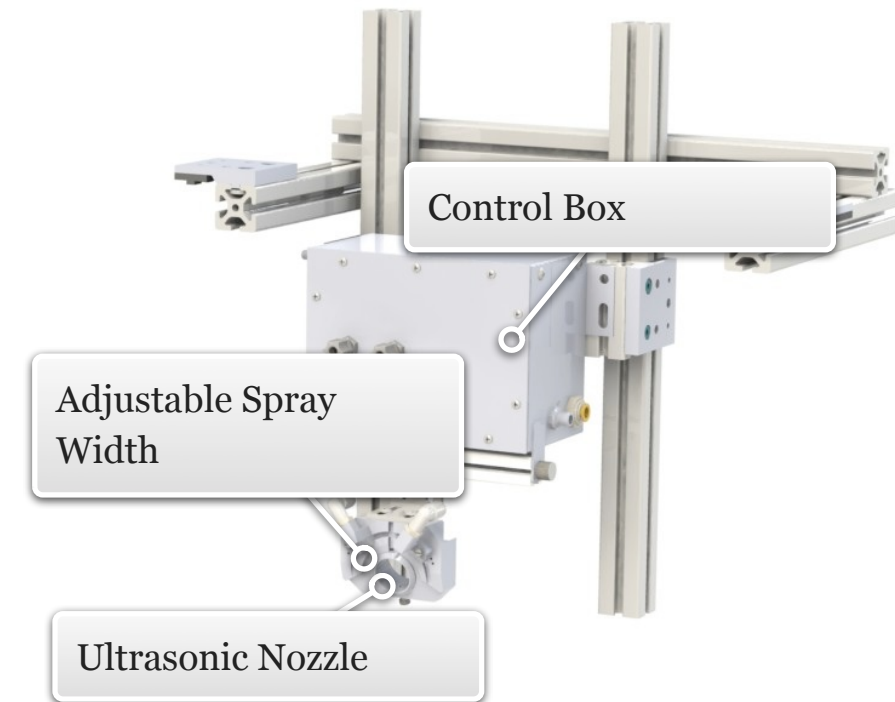
FIGURE 4.4 Ultrasonic Module



### SUMMARY

Ultrasonic spray nozzles are quickly replacing existing spray technologies. They produce an extremely fine mist that results in defect-free thin film coatings with applications in electronics, photovoltaics and batteries. These nozzles reduce overspray and the patterning jets allow for fine control of spray width.

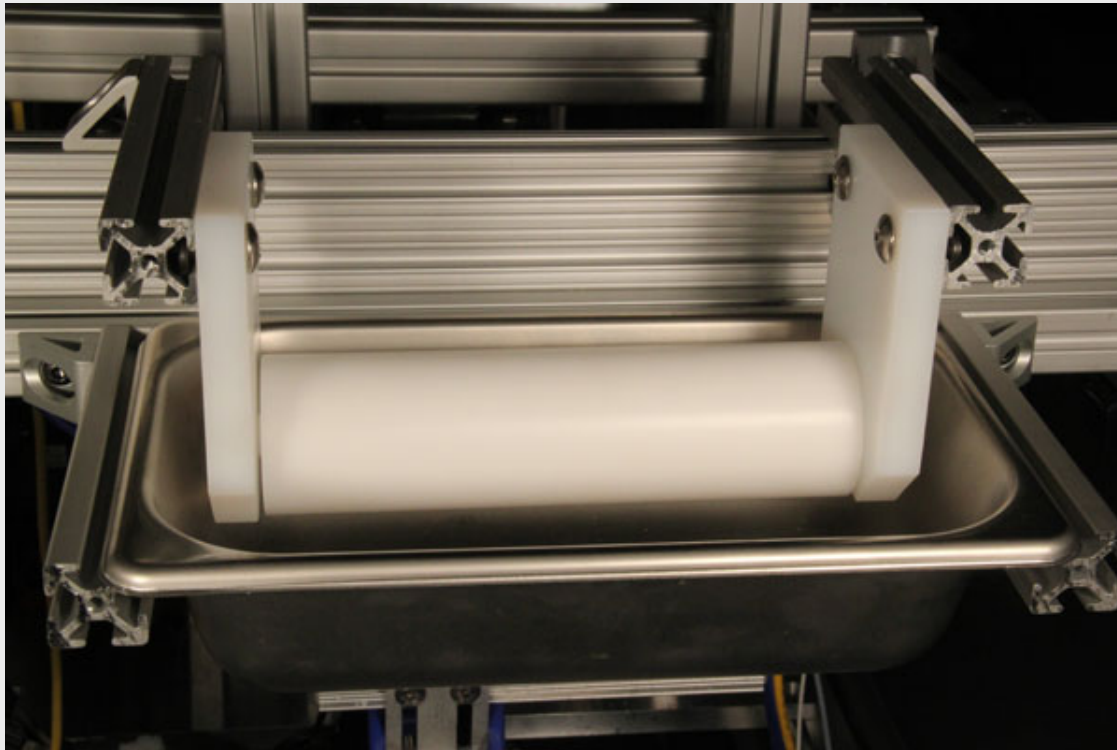
INTERACTIVE 4.4 Ultrasonic Spray Assembly



- **SonoTek Widetrack Ultrasonic System**
- Two ultrasonic nozzles - 48 and 120 kHz
- Controlled spray width up to 24 inches
- Adjustable spray height
- Positive displacement syringe pump
- Adjustable power and flow rate



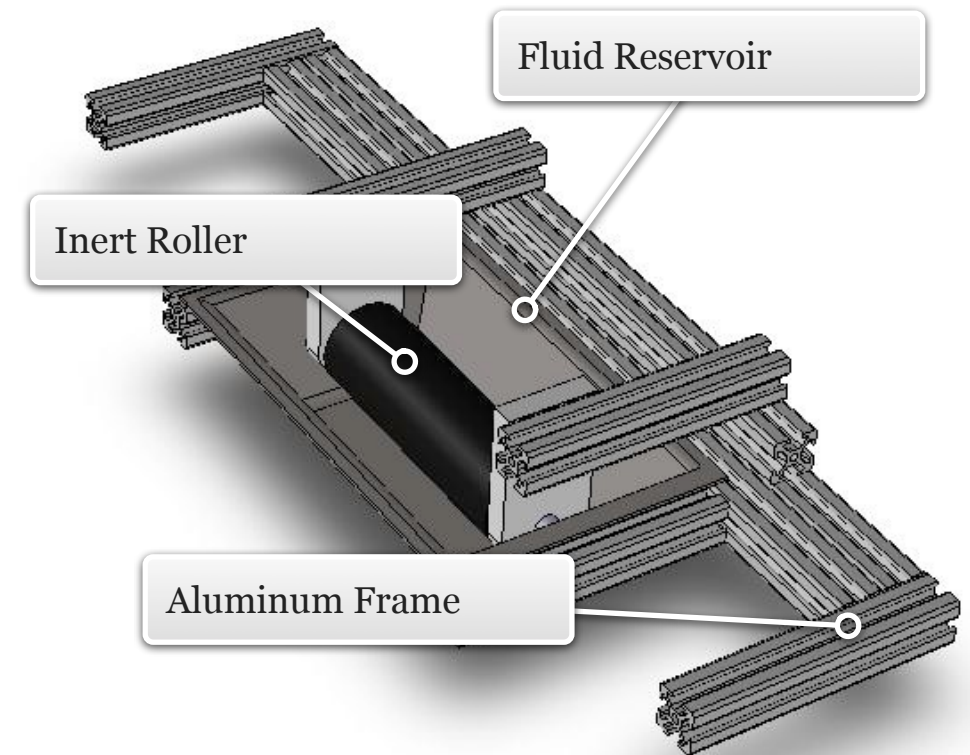
FIGURE 4.5 Dip Module



### SUMMARY

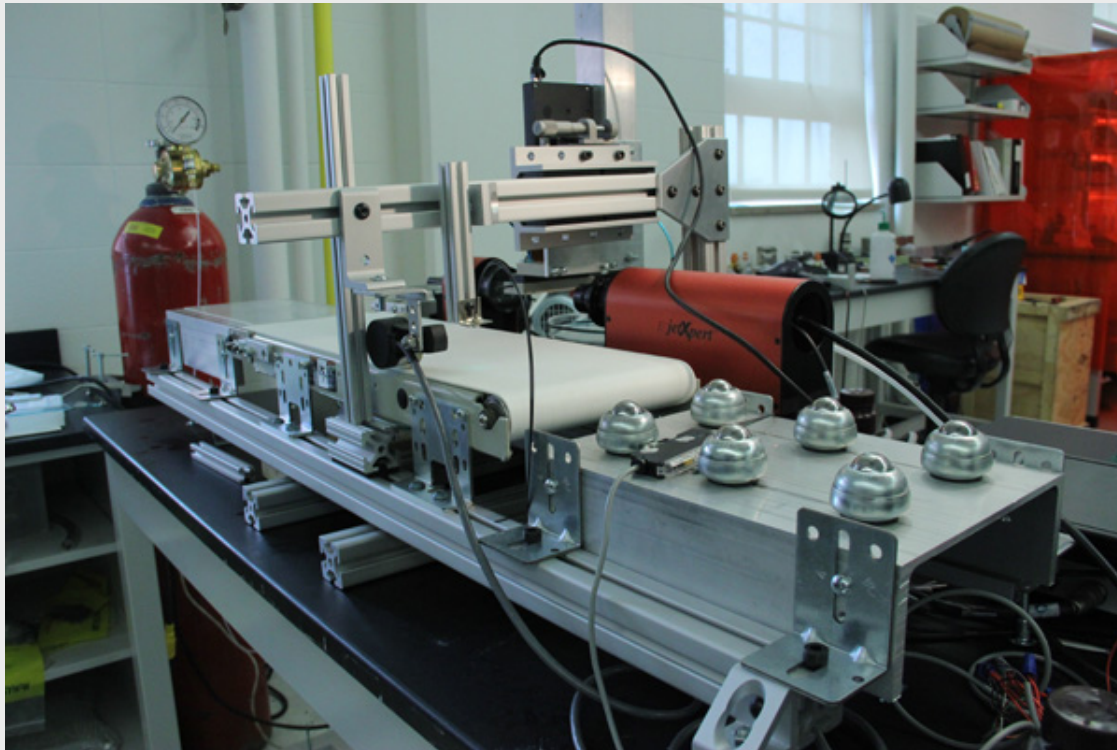
Dip coating is a simple method to clean substrates and apply thin films using evaporation. The process is highly economical and easy to implement for a variety of advanced energy materials. There are four individual dip modules that can be configured linearly for multiple chemistries. These can also be incorporated into an electrodeposition process.

INTERACTIVE 4.5 Dip Coater Assembly



- Chemically inert rollers
- Configurable frame for numerous fluid reservoirs.

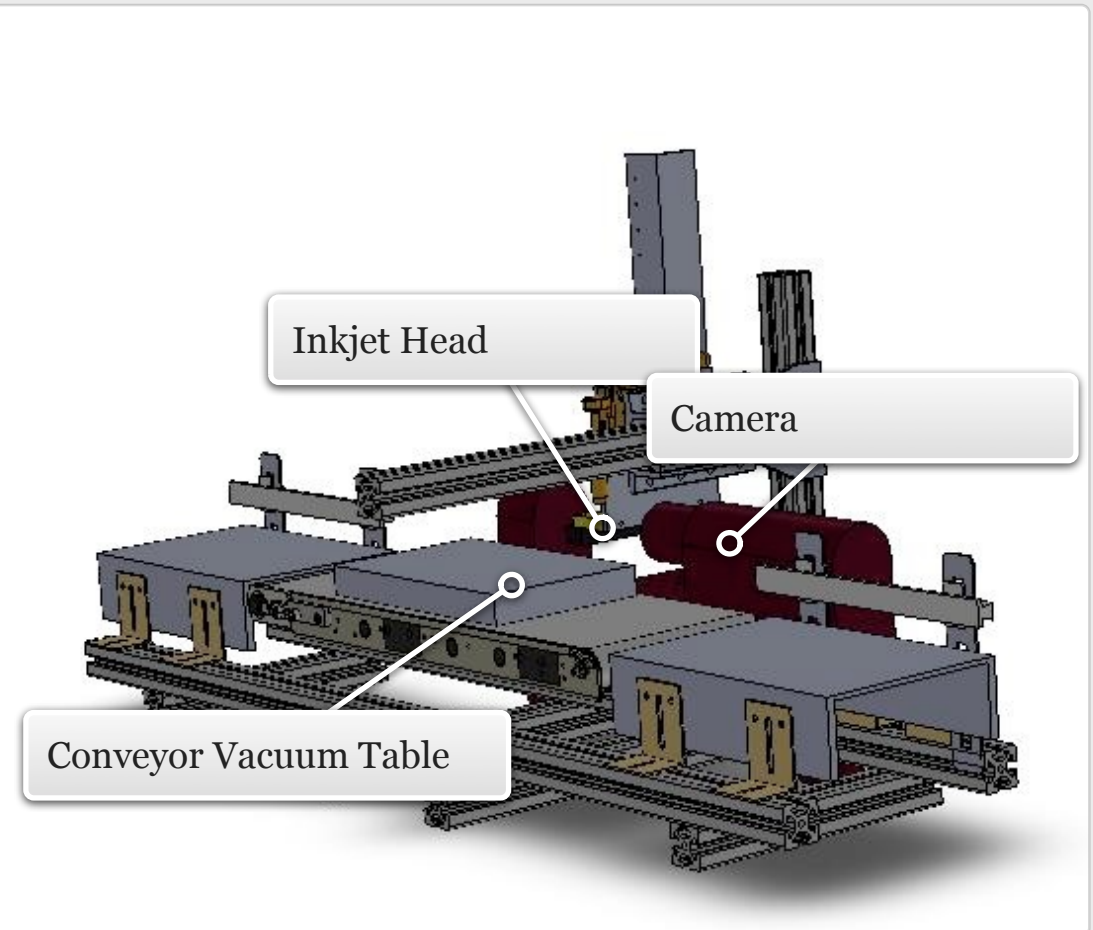
FIGURE 4.6 Inkjet Module



## SUMMARY

Inkjet printing is a valuable processing technology in roll-to-roll applications with the capability to digitally adjust images. Inks are precisely deposited with superb control of droplet size and position, which reduces waste and improves thin film accuracy. This process is widely used in the development of PVs, LEDs, flexible electronics and other devices where precise thin films are desired.

## INTERACTIVE 4.6 Inkjet Assembly

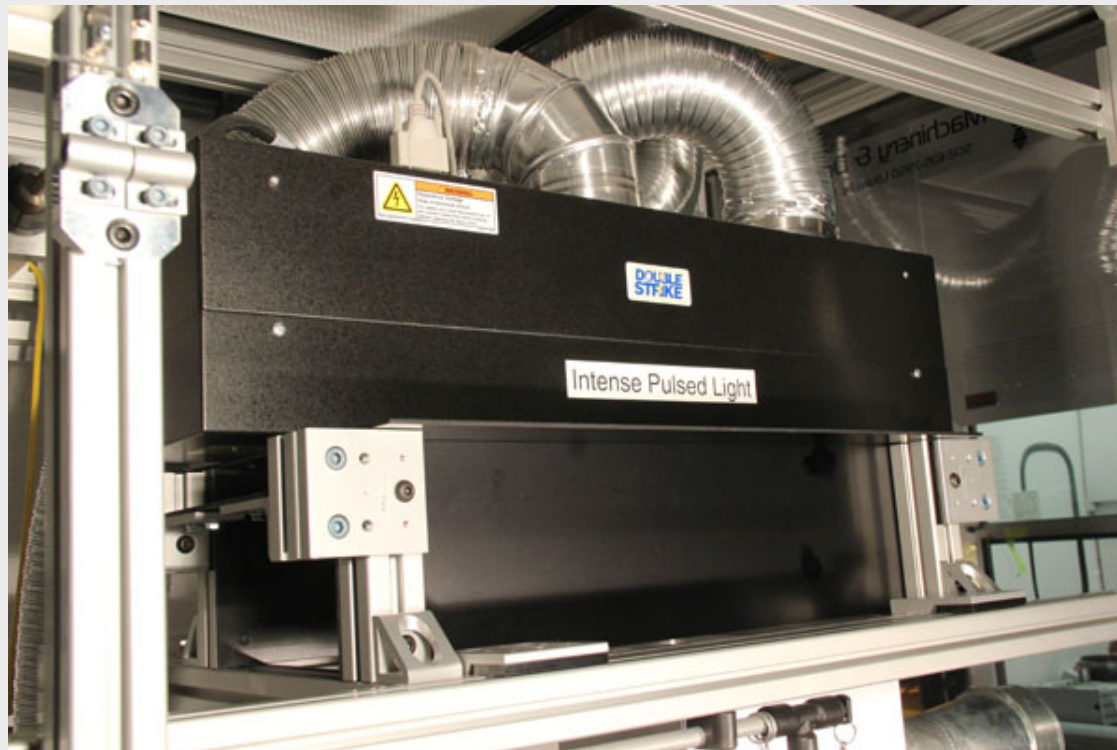


- **Dimatix Spectra Galaxy printhead**
- **ImageExpert imaging tool**
- ImageExpert driver for linear printing
- Flatbed conveyor with vacuum table
- Micro adjustment of head position
- Controlled frequency
- Multiple head configurations available
- Upstream pressure control of ink
- Faculty expertise in ink formulation



## PULSED LIGHT SINTERING

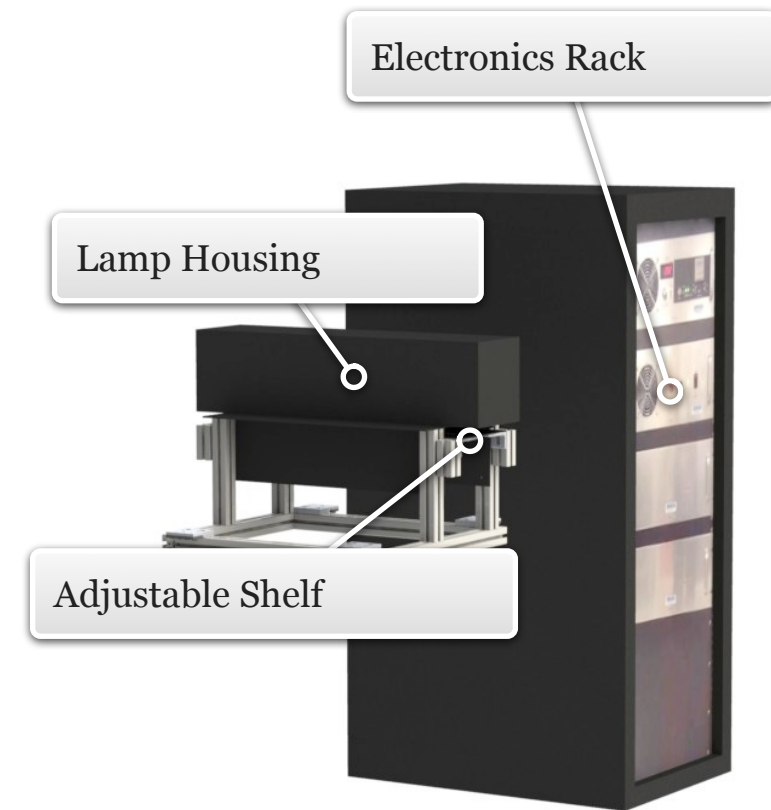
FIGURE 4.7 Intense Pulsed Light Module



### SUMMARY

Sintering nanoparticles using Intense Pulsed Light (IPL) Radiation is a novel technique to fuse high temperature materials using very localized heating. This method has been very successful in thin film electronics in which silver nanoparticles are printed and sintered resulting in conductive patterns on plastic substrates. The low temperature and fast processing makes IPL an important technology for roll-to-roll photovoltaics.

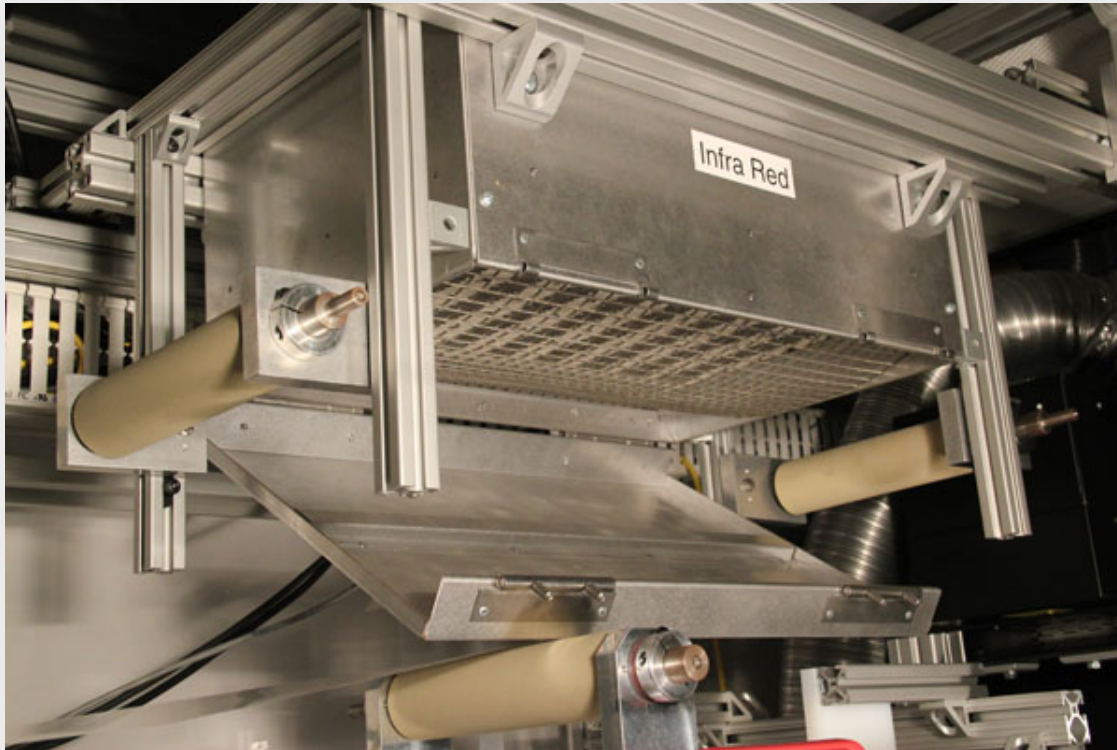
INTERACTIVE 4.7 Intense Pulsed Light Assembly



- **Xenon Corporation Sinteron 2000**
- Selectable pulse duration 580 to 2000 micro seconds
- Adjustable pulse energy 150 - 2000 Joules
- Sintering area 58 cm<sup>2</sup>
- Lamp cutoff 370 and 200 nm

## IR HEATER

FIGURE 4.8 IR Heater Module



### SUMMARY

Infrared (IR) Driers are used extensively in the printing industry to remove water and solvents from a printed ink. The absorption of IR by the thin film through radiative processes makes this a faster option than typical air driers.

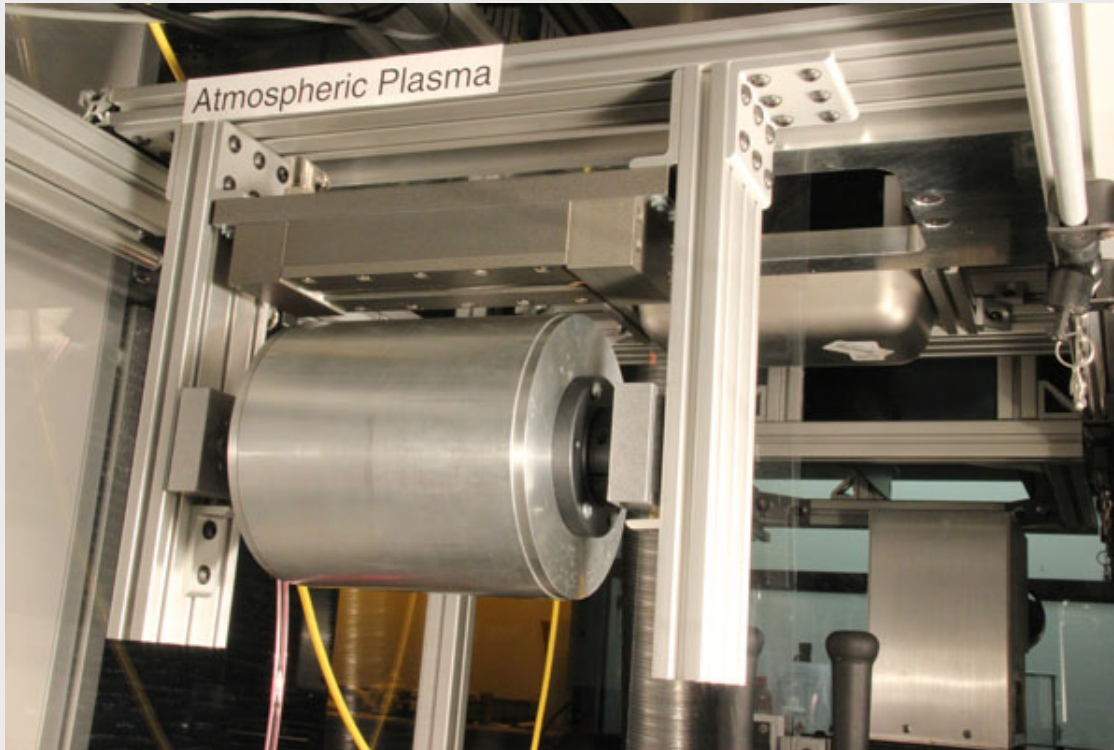
INTERACTIVE 4.8 IR Assembly



- **Driir Infrared drying and heating equipment**
- Solid state triac power controller
- Variable speed fan
- Ample air flow for exhausting solvents



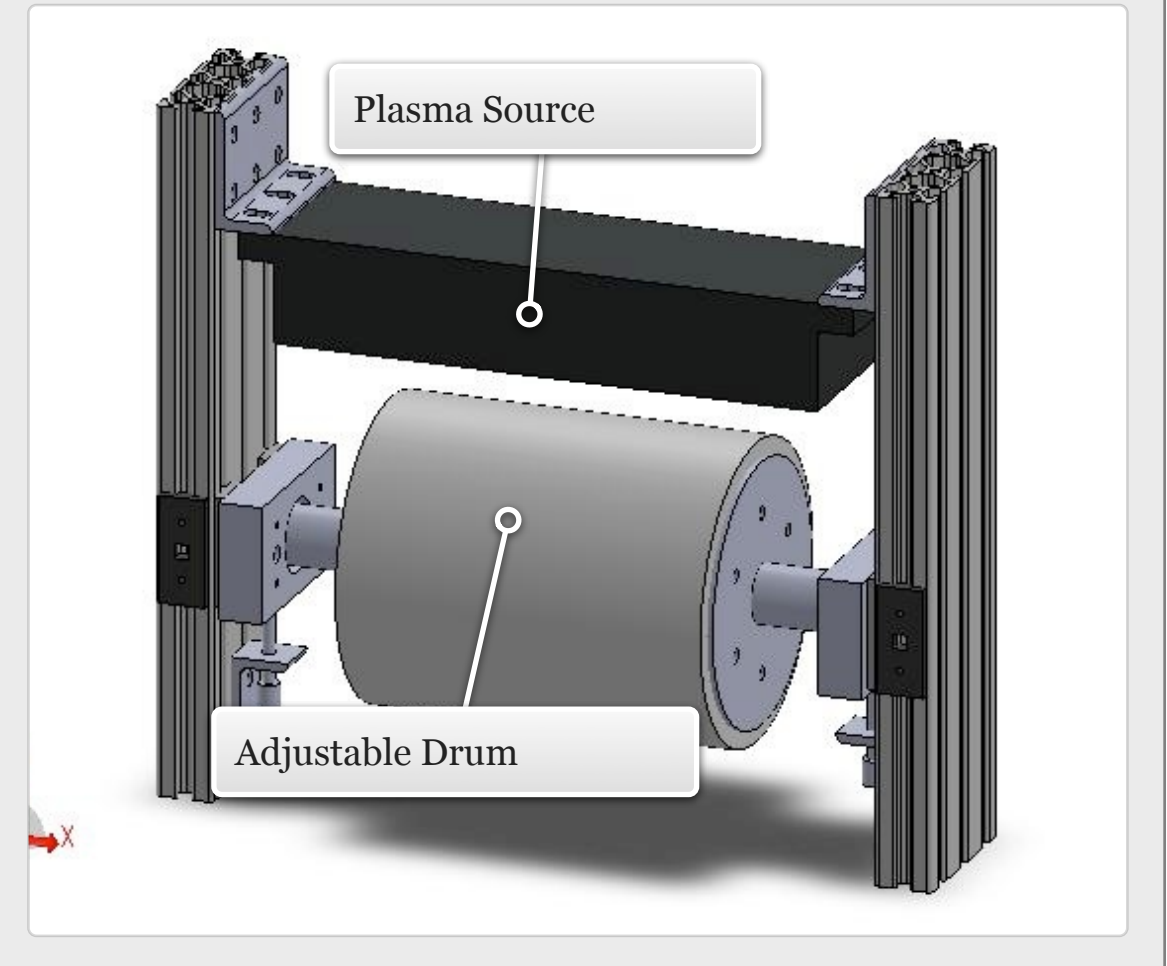
FIGURE 4.9 Atmospheric Plasma Module



### SUMMARY

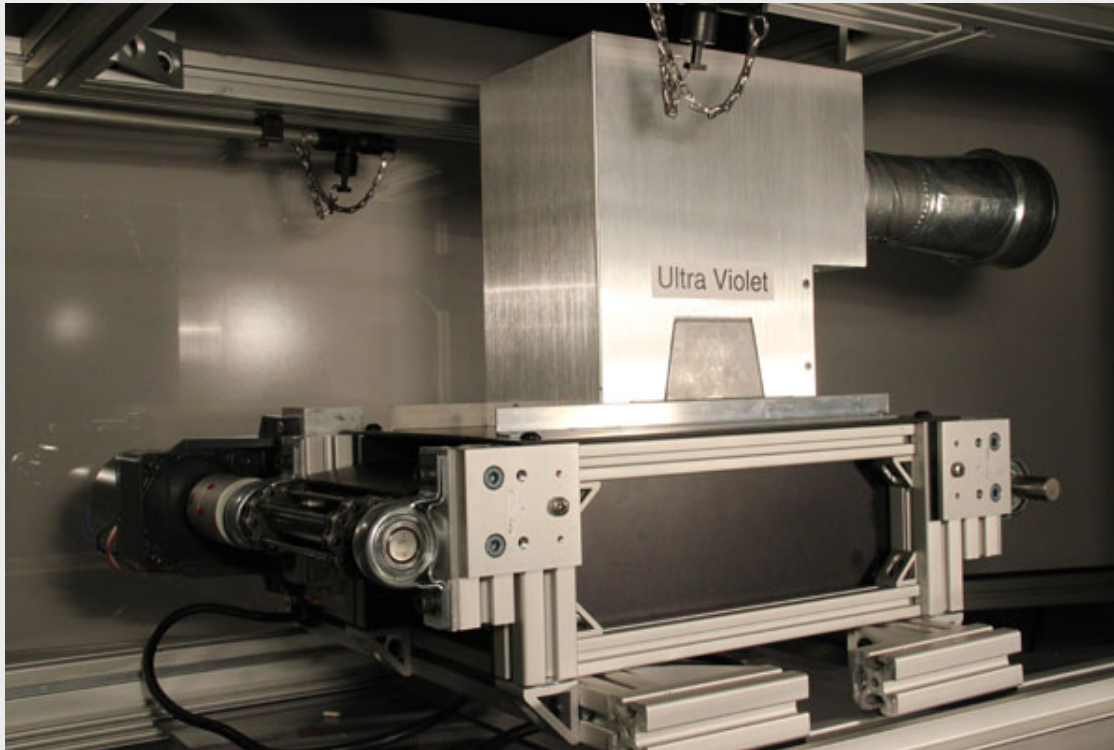
Atmospheric plasmas are typically used for rapid surface treatment of polymer substrates to improve adhesion to coatings. They can also drastically change the surface wettability, improving coating cosmetics. The energetics of the plasma can also be used to produce nanoscaled structures at low processing temperatures.

INTERACTIVE 4.9 Atmospheric Plasma Assembly



- **Plamax 150S Head**
- 600 Watt RF Power Supply
- Ar and O<sub>2</sub> gas mass flow controlled inputs
- Adjustable drum height

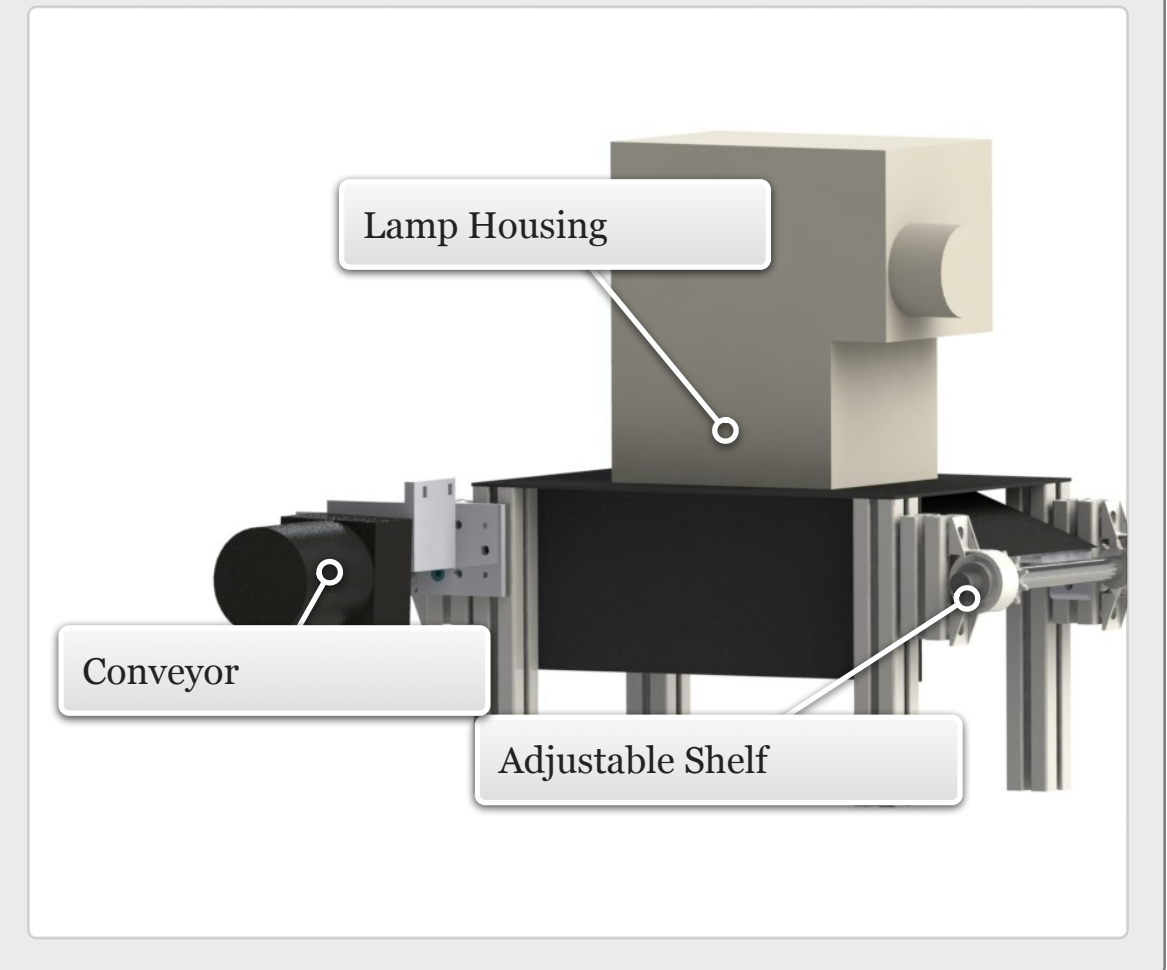
FIGURE 4.10 Ultraviolet Module



### SUMMARY

Ultraviolet (UV) radiation curing is a very popular technique for the printing and coatings industry. The technology replaces costly (energy input and time) thermal curing techniques and is well suited for high throughput roll-to-roll processing. A number of UV curable water borne solutions are now available commercially, making this a more environmentally friendly process.

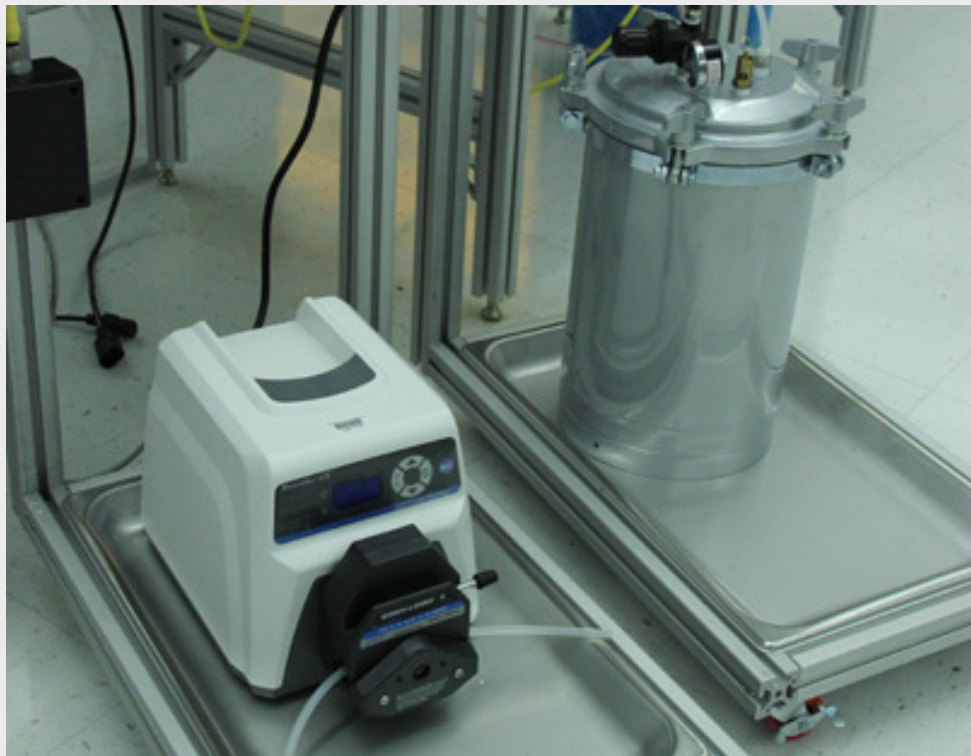
INTERACTIVE 4.10 UV Curing Assembly



- **Fusion Corporation F300S**
- 300 W/in UV bulb
- Several available spectrums
- Web speed control
- Adjustable height between lamp and substrate



FIGURE 4.11 Fluid Delivery Modules



SUMMARY

Many of the atmospheric deposition processes utilized in the roll-to-roll equipment are solution based. In some cases, these will be pumped from a reservoir using discrete metering processes. A number of positive displacement pumps are available to precisely meter solutions with a wide range of viscosities.

PUMP	DESCRIPTION	MAKE/MODEL
Air Tank	2.5 Stainless Steel	
Syringe Pump	Programmable stepper motor syringe pump	
Motor	Remote control 0-600 rpm motor	Masterflex 7528-10
Peristaltic Pump	Easy load Peristaltic Pump	Masterflex 77200-50
Gear Pump	0.56 mL/rev inert gear pump	Masterflex 73004-02
Diaphragm Pump	10-100 mL/min PTFE diaphragm pumo	Masterflex 7090-62
Piston Pump	Stainless steel 100 psi piston pump	Masterflex 7104-62
Micropump	Seal less low flow gear pump	Micropump L3468

- Manual/automatic pressure control
- Manual/automatic motor control
- Inert valving
- Fully integratable with PLC and HMI
- Mounted on roller carts for storage under HEPA enclosure