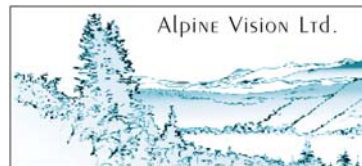


BioWarn Market Survey

PWGSC Contract No. W7701-052726/001/QCL



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ACRONYMS AND ABBREVIATIONS

µm	Micrometer
BBO	Beta-Barium-Borate (b-BaB2O4)
CMS	Cable Management System
COTS	Commercial Off The Shelf
CW	Continuous Wave
DC	Direct Current
DEM	Digital Elevation Model
DP	Diode Pumped
DRDC	Defence Research and Development Canada
GPS	Global Positioning System
HMMWV	High Mobility Multipurpose Wheeled Vehicle
Hz	Hertz
ICP	Iterative Closest Point
IMU	Inertial Measurement Unit
IR	Infra-red
ITAR	International Traffic in Arms Regulations
kHz	Kilohertz
KTA	Potassium Titanyl Arsenate (KTiOAsO4)
KTP	Potassium-Titanyl-Phosphate (KTiOPO4)
kW	Kilowatt
LBO	Lithium Triborate (LiB3O5)
LCD	Liquid Crystal Display
LIDAR	Light Detection And Ranging
MBL	Marine Boundary Layer
mJ	Millijoule
MLPFBM	Mean Laser Pulses Fired Before Maintenance
mm	Millimeter
MOPA	Master Oscillator Power Amplifier
NCAR	National Center for Atmospheric Research

NCPM	Non-Critical Phase Matching
Nd-YAG	Neodymium-Doped Yttrium Aluminum Garnet
NIR	Near Infrared
nm	Nanometer
ns	Nanosecond
OPO	Optical Parametric Oscillator
POB	Point of Beginning
PRF	Pulse Repetition Frequency
PWGSC	Public Works and Government Services Canada
RASCAL	Rapid Scanning Aerosol Lidar
REAL	Raman-Shifted Eye-safe Aerosol Lidar
RFP	Request for Proposal
SHG	Second Harmonic Generation
SOC	Sphere of Confusion
SR-BSDS	Short Range Biological Standoff Detection System
SRS	Simulated Raman Shifting
TBD	To Be Determined
TDP	Technology Demonstration Program
THG	Third Harmonic Generation
UV	UltraViolet
W	Watt
YLF	Yttrium Lithium Fluoride

1 EXECUTIVE SUMMARY

1.1 Laser Source Availability Study

A brief study of commercial off-the-shelf lasers systems was carried out to fill in any gaps in INO's existing knowledge of the laser market. INO's current laser databank is based on an ongoing review of buyer's guides, Internet searches, industrial shows and personal contacts. No off-the-shelf systems were found with the specified requirements nor were any found that combine 355nm and 1.55 μ m. No suitable 310nm source was found off-the-shelf and, to the best of our knowledge, it would not be possible to obtain 5W of power while respecting the other required specifications.

Those suppliers found to be closest to achieving the requirements with a commercial system were contacted. A total of 25 custom laser suppliers were contacted and quotations were received from 9 companies: Thales, Claire Lasers, JMAR Technologies, IB Laser, Photonics Industries, Big Sky Laser, Passat Lasers, RPMC Lasers and QPeak.

Three companies, JMAR Technologies, RPMC Lasers and QPeak, provided quotations or estimates that met all specifications. All systems are dual wavelength systems based on OPO conversion to obtain 1.55 μ m. The exception is JMAR Technologies who supplied alternatives using Raman conversions.

JMAR Technologies is the recommended supplier. **RPMC Lasers** and **QPeak** are the recommended back-up suppliers. These systems meet the client's specifications. All suppliers were informed that the application was military and the client was the Government of Canada.

1.2 3D Scanner Availability Study

The availability of commercial 3D Light Detection and Ranging (LIDAR) scanners applicable to the Defence Research and Development Canada (DRDC) Biowarn project was investigated.

Ten Commercial Off-The-Shelf (COTS) 3D LIDAR scanners were researched and are reported. None of the available scanners approached the Biowarn aperture requirement of 25-36 cm, with most in the range of 3-7 cm and those instruments targeted at terrestrial survey applications at short ranges.

Custom scanners were investigated and a number of one-off systems are described. None of these systems could clearly be identified as complying with Biowarn requirements, although there are lessons to be learned from them.

Consequently, potential solutions involving integration of separate technologies for (a) scanning, and (b) georeferencing were investigated. Research into commercially available beam steering/scanning technologies revealed three U.S.-based commercial providers that could meet the required performance.

An assessment of potential georeferencing techniques was also performed. Integration of COTS equipment and Digital Elevation Models (DEM) with Global Positioning System (GPS) calibration reference points can achieve the required precision for coarse and fine alignment. Scans can then be optimized using the elastic scatter return from the Biowarn system to maintain a scanning height of 0-10 m above the horizon, and to avoid solid obstacles. A visual channel is also recommended to assist in scan optimization.

In summary, the Biowarn pointing requirements and mapping accuracy cannot be obtained with a single available commercial technology, but can be met by integration of available technologies in conjunction with appropriate off-the-shelf components, hardware and software and testing development.

Risk factors appear minimal to achieve the pointing and georeferencing requirements; however, it is recommended that environmental issues be addressed in the form of ruggedness and other factors such as exposure to dust, moisture, etc., if the system is to be deployed on an operational basis.

2 DOCUMENTS

2.1 Applicable Documents

- A-1 W7701-052726/A BioWarn Market Survey RFP, PWGSC, September 22, 2005.
- A-2 W7701-052726/001/QCL BioWarn Market Survey Contract, PWGSC, November 9, 2005.

2.2 Reference Documents

- R-1 “2005 3D Laser Scanner Hardware and Software Survey”, POB (Point of Beginning), <http://www.pobonline.com/>, pp. 72-77, January 2005.
- R-2 “Terrestrial Laser Scanning – New Perspectives in 3D Surveying”, C. Fröhlich and Mettenleiter, M., International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 36, Part 8/W2, October 2004. (http://www.isprs.org/commission8/workshop_laser_forest).
- R-3 “Scanning eye-safe depolarization LIDAR at 1.54 microns and potential usefulness in bioaerosol detection”, Mayor, S. D., S. M. Spuler and B. M. Morley, LIDAR Sensing for Environmental IV, 2005. (NCAR system).

- R-4 “LIDAR road trip uncovers pollution secrets”, IOP Publishing Limited, November 2005, <http://www.optics.org/articles/ole/10/11/2/1>. (RASCAL System).
- R-5 “Scanning LIDAR imaging of marine aerosol fields generated by breaking waves”, Sharma, S. K., B. R. Liemert, J. N. Porter and A. D. Clarke, Environmental Technology Laboratory, R1E/E2, NOAA, US Department of Commerce, <http://www.soest.hawaii.edu/lidar/98lidar.conf.html>(U. of Hawaii system).
- R-6 “Portable Digital LIDAR System”, H. S. Lee, I. H. Hwang, I. Heon and C. R. Prasad, U.S. Patent No. 6,593,532, July 15, 2003. (SESI patent).
- R-7 “Efficient integration of aerial and terrestrial laser for virtual city modeling using lasermaps”, J. Böhm and N. Hazla, ISPRS WG III/3, III/4, Vol. 3, Workshop “Laser scanning 2005”, Enschede, The Netherlands, Sep 12-14, 2005. (Stuttgart work).
- R-8 “Terrestrial laser scanning – new perspectives in 3D surveying”, C Frölich and M. Mettenleiter, Int. Arch. Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVI-8/W2, NetScan Conference, Freiburg, Germany, October 3-6, 2004.
- R-9 “Processing of point cloud from laser sensors”, ISPRS Commission III/3, 2004, http://www.itc.nl/isprs wgIII-3/resources_links.html.

3 INTRODUCTION

The goal of the BioWarn TDP is to demonstrate the capability, using a ground based 3D LIDAR scanner, to detect and monitor aerosolized biological threats over wide areas. To achieve this goal, two main challenges have been identified: the commercial availability of an adequate laser source; and the capability of commercially available 3D scanners to interface human users with the surrounding landscape in order to establish aerosol cloud surveillance at a low height relative to the ground and over complex terrains.

MacDonald Dettwiler had prime responsibility for this study, reviewing and integrating the study results and managing the overall project.

National Optics Institute (INO) performed the laser market study.

Alpine Vision performed the scanner market study.



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4 LASER SOURCE AVAILABILITY STUDY

4.1 Introduction

This section of the report presents the results of work done to source a laser system corresponding to the specifications stated in Section 4.2. Section 4.3 summarizes the survey of commercial off-the-shelf systems. Section 4.4 presents the results of the custom laser sourcing. Section 4.5 presents the results for the 310nm source.

4.2 Requirements

The laser system should meet the following specifications:

- Wavelengths: 355nm and 1.55 μ m, not produced simultaneously. Adding 310nm is a plus
- Pulse repetition frequency: 100 Hz to 1 kHz
- Average output laser power: >5 W (with either wavelength)
- Volume: <1 cubic metre (all components included)
- Sufficiently robust for fielded operation (with client-provided limited environmentally-controlled enclosure)
- Laser pulse duration: 5 to 20 ns
- Mean laser pulses fired before major maintenance: 10^9
- Total electrical power consumption: <5 kW

4.3 Survey of Commercial Off-The-Shelf Lasers

This study was brief and served to fill in any gaps in INO's existing knowledge of the laser market. INO's current laser databank is based on an ongoing review of buyer's guides, Internet searches, industrial shows and personal contacts. No COTS were found with the specified requirements nor were any found that combine 355 nm and 1.55 μ m.

Table 4-1, Table 4-2, Table 4-3 and Table 4-4 present a representative sampling of the commercial lasers that approach the requirements. The tables are grouped according to the laser pump type and with another section for 1.55 μ m. The outlier specification responsible for a given laser's elimination is highlighted in the table. The specifications sheets from the different vendors are found in Appendix A.

For the Continuous Wave (CW) diode pumped Neodymium-Doped Yttrium Aluminum Garnet (Nd-YAG) lasers, the lifetime is not supplied by manufacturers but is usually implicit and more than 10 000 hours. This operating lifetime corresponds to 3.6×10^9 pulses @ 100Hz and 3.6×10^{12} pulses @ 100kHz. It should also be understood that industrial lasers are meant to work between 15 and 35°C.

For the flashlamp pumped Nd-YAG laser, the maximum flashlamp lifetime is around 30 to 40 million pulses. This is the number of pulses before power drops to 70% – 90% of its original value, depending on the manufacturer. These comments also apply to the Optical Parametric Oscillator (OPO) systems pumped by a flashlamp.

Those lasers that require a water inlet will need a closed loop chiller. Those units that are water-cooled cannot be operated at or near water's freezing point.

OPOs are usually designed to be wavelength tunable and thus often require 355nm pumping for greater wavelength coverage. This reduces substantially the power that can be achieved and thus the number of possible vendors of 5W-1550nm OPO systems.

The Centurion from Big Sky Laser appears to be the COTS 355nm laser which most closely matches the specified requirements, although the JMAR laser is also interesting. The Centurion can also be ordered with ethylene glycol for the chiller instead of water and thus can be used in a large temperature range.

Table 4-1 CW Diode Pumped Nd-YAG¹

Manufacturer	Model #	λ (nm)	Energy per Pulse (mJ)	PRF (kHz)	Laser Pulsewidth (ns)	Average Power (W)	Laser Head Dimensions (mm)	System Components Dimensions (mm)	Fieldable	MLPFBM (i.e. hours of operation)	Power Consumption (W or V/A)
Quanta System	Formula	1064	1 @ 10kHz	0-100	6-20	10 @ 10kHz	186x166x103	414x275x197	Industrial laser	>10000	Max. 600 (air cooled)
Photonix Industries	DS20-351	351	5 @ 1kHz	0-10	35	5 @ 1kHz	191x600x127	483x476x133 and 483x432x178	Not known	Not available	110V/20A or 220V/10A
Photonix Industries	DS40-355	355	0.8 @ 10kHz	0-50	40	8 @ 10kHz	191x600x127	483x476x133 and 483x432x178	Not known	Not available	110V/20A or 220V/10A
EKSPLA	NL220	355	3	1	24-27	3	730x210x120	500x452x145	Industrial laser	Not available	<1000
Spectra Physics (Newport)	Navigator I J40 X15SC	355	0.075@ 20kHz	15- 100	15	1.5 @ 20kHz	727x113x227	455x429x176	Industrial laser	Not available	Not available
Coherent	Avia355-4500 or Avia X	355	0.18 @ 25kHz	0-100	<30	>10 @ 60kHz	762x203x165	452x434x254	Industrial laser	Not available	Max. 1100
JDSU	Q301-HD	355	1 @ 10kHz	0-250	34 @ 10kHz	>10 @ 10kHz	812x140x127	427x364x88 and 440x533x264	Industrial laser	Not available	<1000 (700 typical)

¹ Shaded cells indicate specifications that do not meet requirements



Table 4-2 Pulsed Diode Pumped Nd-YAG²

Manufacturer	Model #	λ (nm)	Energy per Pulse (mJ)	PRF (Hz)	Laser Pulsewidth (ns)	Average Power (W)	Laser Head Dimensions (mm)	System components Dimensions (mm)	Fieldable	MLPFBM	Power consumption (W or V/A)
JMAR	BriteLight	1064 (THG optional)	250	500	0.8 (Longer pulses optional)	125 (24 and 60W versions available)	610x914x305	483xNAx1220	Not known	10 ⁹	Not known
Thales	Jedi	532	>120	100	<15	>12	735x175x250	780x600x800	Not known	10 ⁹	230V/20A/50 or 60Hz
Big Sky Laser	Centurion	355	>10	0-100	<8	>1	127x76x229 +fans and fins	2U 19" rack mount unit	Yes	10 ⁹	300
IB Laser	DiNY pQ	355	1.5 @ 500Hz	<1000	<8	<1	405x120x90	530x553x600	Industrial laser	Not known	110V/16A or 230V/8A
IB Laser	DiNY pQ TITAN	1064/ 532 available	Up to >100 @ 1064nm	100- 2000	10	Option	Not known	Not known	Industrial laser	Not known	Not known
CEO (Northrup Grumman)	Repeat-a- Pulse	1064	>3	10-30	20	Very low	Not known	Not known	Not known	Not known	Auto-ranging
Lee Laser	LDPP	—	—	—	>50000	—	—	—	Industrial laser	—	—

² Shaded cells indicate specifications that do not meet requirements.

Table 4-3 Flashlamp Pumped Ng-YAG³

Manufacturer	Model #	λ (nm)	Energy per Pulse (mJ)	PRF (Hz)	Laser Pulsewidth (ns)	Average Power (W)	Laser Head Dimensions (mm)	System Components Dimensions (mm)	Fieldable	MLPFBM	Power Consumption (W or V/A)
Quanta System	Thunder TWO	355	550 @10Hz	0-20	<8	5.5 @10Hz	875x376x222	900x385x700	Not known	See Section 4.3 text	Not known
Thales	Saga 120/10	355	350	10	4-8	3.5	1100x188x288	65x120x190 495x430x790 495x215x715	Not known	See Section 4.3 text	230V/20A
Thales	Saga 230/10	355	600	10	4-8	6	1100x188x288	Same sizes but needs water inlet	Not known	See Section 4.3 text	230V/20A
Big Sky Laser	CFR 800	355	125	20	<10	2.5	146x165x366	585x286x592	Yes	20x10 ⁶	Not known
EKSPLA	NL310	355	490	10	<4-6	4.9	250x190x790	550x530x590 (needs water inlet)	No	See Section 4.3 text	<3.5kVA
Continuum	Powerlite Precision II 9020	355	475	20	3-7	9.5	1190x457x300	715x622x922 (needs water inlet)	No	See Section 4.3 text	220V/21A single phase

³ Shaded cells indicate specifications that do not meet requirements.



Table 4-4 Nd-YAG Pumped OPO⁴

Manufacturer	Model #	λ (nm)	Energy per Pulse (mJ)	PRF (Hz)	Laser Pulsewidth (ns)	Average Power (W)	OPO Dimensions (mm)	System Components Dimensions (mm)	Fieldable	MLPFBM	Power Consumption (W or V/A)
Quanta System	Tinto	>1550	Up to 150 @20Hz	0-20	<6 if pumped Thunder TWO	3 @20Hz	410x120x140 (add-on accessory)	None other than for the pump laser	Not specified	Not known	None for the OPO
Big Sky Laser	CFR 800 - OPO	1574	135	20	<10	2.7	146x165x95 (add-on accessory)	None other than for the pump laser	Yes	20x10 ⁶	None for the OPO
Big Sky Laser	Centurion - OPO	1574	7	100	<10	0.7	TBD	None other than for the pump laser	Yes	10 ⁹	None for the OPO
Photonics Industries	DS20-OPO	>1550	2 @ 1kHz	0- 50000	15	2 @1kHz	191x600x127 (intracavity conversion so laser is necessary)	483x476x133 + 483x432x178	Not specified	>10000 hours	110V/20A
Continuum	Surelite OPO Plus Pumped with SLIII- 10	1550	Up to 60	10	3-7	0.6	458x197x178	None other than for the pump laser	Unlikely	Not known	None for the OPO

⁴ Shaded cells indicate specifications that do not meet requirements.

4.4 Custom Lasers

Those suppliers found to be closest to achieving the requirements with a commercial system were contacted. A total of 25 custom laser suppliers were contacted (see Appendix B) and supplied with the specifications sheet (see Appendix C). Quotations or estimates were received from 7 companies: Thales, Claire Lasers, JMAR Technologies, IB Laser, Photonics Industries, RPMC Lasers and QPeak. Three other companies have indicated their interest but have not presented an estimate at this time: Photonics Industries, CEO and Big Sky Laser. The quotations and estimates received are found in Appendix D. All suppliers were informed that the application was military and the client was the Government of Canada. The following paragraphs resume our findings. Table 4-5 summarizes the custom lasers based on the required specifications and Table 4-6 summarizes the cost, technical approach and relative risk for each quotation received.

Big Sky Lasers has a COTS laser system delivering up to 1.5W at 355nm and at 100Hz and an OPO system (0.5 to 0.7W) designed for military use. The price tag for these systems is \$45k (US) and \$55k (US) respectively. They expect it to pass integrity tests as per Mil Spec 810E. The system could be air-cooled, i.e. no liquid coolants. They also have experience in vehicle-mounted lasers. However, no estimate has been received as of yet, more than two months after first contact. In addition, contact with those responsible is arduous (our request is now in the hands of the company's president).

The Thales laser is not powerful enough and not considered a field instrument and is therefore not recommended.

Our interactions with Claire Lasers did not inspire technical confidence. They have not fabricated anything similar in the past, seem very confident and yet their cost estimate is the lowest which is a warning flag. Their knowledge of the major issues related to the realization of such a system seems limited. The laser platform they intend to use for the main oscillator was tested at much lower repetition rates than what is required by the application. This supplier is not recommended.

The system proposed by Photonics Industries meets all the requirements for the applications, however two major issues lead us to reject their offer. Firstly, the development cost is very high (850 K\$ USD), and secondly, the guaranteed average output power of 5 W is achieved at 1kHz. At a lower repetition rate of 100Hz, which is preferable for the application, the average power decreases to 0.5 W at both wavelengths (1.55 um & 355nm).

IB Laser's cost estimate of \$2million eliminated serious consideration of their bid and no further discussions were held with them.

Big Sky Laser's cost estimate of \$1million USD eliminated them from serious consideration. It should also be noted that an enormous effort was required to obtain this information.

Passat Laser's cost estimate of \$1million eliminated serious consideration of their bid and no further discussions were held with them.

JMAR Technologies proposed two conversion approaches, OPO and Raman. The risk was put at medium for the Raman approach with respect to the OPO approach simply because of their inexperience with the former. The Raman approach is attractive, however, because of conversion efficiency is much greater than with an OPO for the required 10^9 shots (before maintenance). The Stimulate Raman Shifting (SRS) cell would be deuterium gas instead of methane in order to avoid the soot generation common with a methane cell. The Raman cell may also be less susceptible to aging than an OPO crystal although there are tuning techniques with the latter that mitigate aging effects. This was not investigated further as it is outside of the scope of the current work. JMAR's proposal is based on their commercial off-the-shelf BriteLight system while the OPO is sub-contracted to OPOTEK and the Raman cell to Light Age. The converter description is in Appendix D. The fact that their system uses virtually all COTS components is very attractive. The proposal meets all technical specifications. The company has a slightly more complex laser oscillator than others and no experience in vehicle mounted systems, however, this supplier is recommended and ranked number 1 for the reasons enumerated below:

- Diode pumped low repetition frequency COTS Nd-YAG laser with up to 125W average power @ 500Hz @ 1064nm.
- Modular cascable (and thus upgradeable) amplifiers, giving lasers from 1W to 125W average power.
- Pulse width can be ordered from less than 1 nanosecond to close to 200ns (price estimate is for 5ns).
- Pulse width selection would permit optimization of wavelength conversion efficiency.
- JMAR is experienced in high pulse energy and high peak power wavelength conversion.
- Respects all stated requirements.
- Guarantees more than 2 billion shots for the laser diodes.
- JMAR is aware of optical damage and aging to conversion crystals with respect to peak power.
- Laser system has active beam pointing stabilization.
- JMAR is very conservative with respect to conversion efficiency in OPO. Pulse energies at 1.55 μ m should be significantly larger than those quoted, especially with the beam quality that was quoted.

- JMAR showed real interest in answering our demands with sufficient technical information and in a timely manner.
- JMAR is the only company proposing more than one option for converting to the eye safe wavelength. Light Age's Raman converters could be the best option for a robust and energy efficient system.
- JMAR would sub-contract the OPO or the Raman converter to other companies with better expertise in the domain, minimizing risk and optimizing performance and cost.
- Major components are COTS, so International Traffic in Arms Regulations (ITAR) regulations less of a problem.
- JMAR is proposing a rapid electro-optic switch for going from 355nm to 1.55 μ m.

Note that in JMAR's document (see Appendix D) in Table 1, the second column and third line should read >10W.

RPMC's proposal meets all technical specifications and provided excellent customer service. They took care to estimate the price difference between a system at 200 Hz and one at 1 kHz. An estimate for a 200-Hz laser system emitting twice the required average power was also provided. Although they claim to have delivered diode-pumped lasers emitting up to 800 mJ in the past, their quotation as well as our interactions were not as detailed as other suppliers. Our confidence in their quotation is therefore diminished, which is why the risk was evaluated as medium. They are recommended and ranked number 2.

QPeak's proposal also met all technical specifications and the technical details provided inspired confidence. They claim to have delivered similar systems in the past. The customer service was not as high as RPMC, however. They are recommended and ranked number 2.

In a final note, it will be necessary before purchasing to define what "major maintenance" means. For the pump diodes, the number of shots fired is specified with regards to a reduction in output power of the fundamental wavelength (1064nm usually). This reduction could be different from one vendor to another. Additionally, the output power from the 355nm and 1.55 μ m beams might fall faster than that of the fundamental. The conversion crystals need to be in a controlled environment, which is usually the case (they usually are in a temperature controlled mount). The laser pulses will affect these crystals. There is, usually, long term optical damage. Some systems have a translation mechanism to spatially move the crystal volume in which the conversion takes place. The number of pulses at the wavelengths of interest will need to be guaranteed if the wavelength conversion crystals are not to be changed before the pump diodes. We have not had confirmation of any vendor having operated an OPO system for the number of pulses and pulse energies specified in the requirements.



Table 4-5 Custom Laser Specifications

Manufacturer	λ (nm)	Energy per Pulse (mJ)	PRF (Hz)	Laser Pulsewidth (ns)	Average Power (W)	Laser Head Dimensions (mm)	System Components Dimensions (mm)	Fieldable	MLPFBM	Power consumption (W or V/A)
Thales laser	355 1590	> 30 > 25	100	< 15	> 3 > 2.5	735 x 250 x 175	960 x 800 x 600 700 x 350 x 120 (0.522 m ³ total)	Not guarantee d	1.064 μ m oscillator: 10 ⁹	5kW
Claire Lasers	355 1540	60 60	100 100	5 5	6 6	N/A	< 1m ³ total	Yes	10 ⁹	< 5kW
RPMC Lasers	355 nm 1570 nm	25 25	200 200	tbd tbd	> 5 > 5	N/A	< 1 m ³ < 1 m ³	yes yes	> 10 ⁹ > 10 ⁹	< 5 kW < 5 kW
Q-Peak	349 nm 1504 nm		500 500	15 ns 15 ns	> 5 > 5	N/A	< 1 m ³ < 1 m ³	yes yes	> 10 ⁹ > 10 ⁹	< 5 kW < 5 kW
JMAR Technologies	355 1550/OPO 1550/Raman	>33 >3 >15	300 300 300	5@1064nm 5@1064nm 5@1064nm	>10 >1 >5	N/A	< 1 m ³	Yes Yes Yes	10 ⁹ 10 ⁹ 10 ⁹	<5kW -- --
Photonics Industries	355 1550	>5 > 0.5 >5 > 0.5	1000 100 1000 100	Between 5-20	> 5 > 0.5 > 5 > 0.5	Total system with chiller < 1m ³	320 x 606 x 511	Yes	10 ⁹	< 5kW
IB Laser	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Big Sky Laser	355 nm 1.5 μ m	50	100	N/A	5	N/A	N/A	Yes	10 ¹⁰ , not guaranteed	2.5 kW
Passat Laser	355 nm 1599 nm	75	256	N/A	5	900 x 900 x 600	< 1 m ³	Yes	10 ⁹	< 5kW

